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CONCEPTUAL DESIGN STUDY REPORT

V/STOL JET OPERATIONS RESEARCH AIRPLANE DESIGN STUDY

by

G. Rosenthal, J. Chung,
E. Schiller, and J. Wright

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Prepared under Contract No. NAS1-6778 by
FAIRCHILD HILLER CORPORATION
Republic Aviation Division
Farmingdale, New York 11735

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This report contains the results of conceptual design studies completed and originally presented at the end of Part II of a three-part study. Only minor updating and editorial corrections have been applied to the preliminary version of this report. These were primarily incorporated to improve the clarity of the presentation.

Since publication of the preliminary report, further detailed preliminary design effort has been directed towards Concept C. Consequently some minor modifications have been made to the engineering data of this concept, and these are reported in the Aircraft Preliminary Design Report (FHR Report 3324-21) as part of the requirements of this study. However, these data and engineering modifications do not significantly affect the relative comparisons and conclusions of the present report and, therefore, it is being reissued with only minor editorial corrections.

SUMMARY

This report summarizes the results of a conceptual design study performed by the Fairchild Hiller, Republic Aviation Division, under Contract No. **NAS1-6778.** This effort represents Part II of a three-part study. Part I of the study was devoted to trade-off studies that resulted in recommendations for finalized aircraft design requirements. Part III of the study will include intensive preliminary design and program planning for the selected aircraft concept.

Four new designs and three modified aircraft candidate concepts, and two lift engine models have been evaluated to determine their suitability for a V/STOL jet operations research aircraft. These candidate concepts were evaluated in terms of finalized specifications provided by the NASA that followed contractor trade-off studies performed in Part I. One new design, Concept C, and one modified existing aircraft design, Concept J, were selected as most suitable for intensive preliminary design studies. As a result of the parametric study, the General Electric YJ85-GE-19 engine was selected as the most appropriate lift engine to incorporate in both design concepts. The same engine model was specified by the NASA to be the lift-cruise engine at the outset of the study.

In Concept C, two lift-cruise engines are located in the overwing-nacelles and six lift engines are arranged in two longitudinal rows. These engines are closely grouped about the center of gravity. The lift-cruise engine exhausts are diverted through a valve and a curved tailpipe through the fuselage to form, with the lift engines, a rectangular array of eight exhaust exits in the vertical lift mode. This midwing configuration has cockpits in tandem, and satisfies the requirements for visibility and cockpit displays. The aircraft has a hover endurance of 14.0 minutes and a design VTO gross weight of 15,300 pounds.

Concept J uses a modified North American stretched Sabreliner airframe with two lift-cruise engines located in the overwing nacelles and eight lift engines arranged in two longitudinal rows in the fuselage close to the center of gravity. The lift-cruise engine exhausts are diverted through a valve and curved tailpipe. In the vertical lift mode a rectangular array of ten jet exhausts is formed by the two lift-cruise engines and the eight lift engines. This low wing configuration has a side-by-side cockpit.

An evaluation of the new and modified aircraft (Concepts C and J) indicates that Concept C will provide a significant improvement in research utility. The gain in research utility is achieved with a negligible difference in delivery schedule and a nominal difference in total program cost.

INTRODUCTION

Requirements have been issued by the NASA, Langley Research Center, for a conceptual jet V/STOL aircraft to explore the deficiencies in the technology of such aircraft in V/STOL handling qualities and operation in the terminal area. These requirements specifically cover hover endurance, hover control, lift thrust, vectoring capability, stall speeds, structural criteria, pilot visibility, cockpit display, and ease and suitability of conversion to a pure lift mode. A summary of requirements is presented on page 3.

The lift-cruise engine type specified to be included in the study was the General Electric YJ85-GE-19 engine. Two lift engine candidates were specified for the study, the Rolls-Royce RB162-81 and the same General Electric YJ85-GE-19 type. These were specified on the basis of their availability and suitability of their thrust levels. The discussion of the relative merits of the lift engine types is presented on page 5, and selection of one type is discussed on page 20.

A brief discussion of methods of evaluation of the various concepts is presented on page 4. This is followed by a comparison of candidate lift engine characteristics on page 5.

The candidate concepts are described and depicted in the section beginning on page 6. The reasons for selecting the various concepts for continuation in the study are also presented.

The candidate concepts were intensively evaluated in terms of hover endurance, control capabilities, and their suitability for the pure lift mode of research. Each concept was considered with several different complements of engines, and the aircraft sized for a range of gross weights to yield different levels of hover endurance. A maximum cut-off VTO gross weight was found for each concept and complement of engines in terms of a single-engine out capability or other critical control limit. This section begins on page 11.

The rationale for selection of the General Electric YJ85-GE-19 lift engine is presented in the section beginning on page 20.

A summary of the relative merits of the concepts intensively studied follows on page 21. The rationale used for selection of Concept C is also included.

The major differences between the new aircraft (Concept C) and the modified existing aircraft (Concept J) are compared in terms of physical geometry, weights and balance characteristics, structural criteria, aerodynamic performance, flying qualities, propulsion and thermodynamics, projected subsystems, and program plans.

The new aircraft, Concept C, was found to provide superior research utility with greater confidence in attainment of program and performance goals and more flexibility of operation.

V/STOL RESEARCH AIRCRAFT REQUIREMENTS

The requirements summarized below are the results of the Part I trade-off analyses performed involving the variables outlined in the Statement of Work, as well as evaluations of the desired features included therein.

Hovering Endurance. - The aircraft shall be designed for at least 12 minutes hover time. Provisions for overload fuel, corresponding to one minute at hover power, shall be made to allow for warmup and checkout before take-off. This fuel shall not be included in the design gross weight.

VTOL Performance. -The VTOL performance shall be achieved at sea level on an 80 degree Fahrenheit day. With all engines operating and with 50 percent of maximum control about all axes applied simultaneously, the ratio of net hover lift to design gross weight shall not be less than 1.15 out of ground effect. With 80 percent of the maximum control about the most critical axis and 50 percent about the other axis applied, the ratio of net hover lift to design gross weight shall not be less than 1.05 out of ground effect. The ratio of net hover lift to design gross weight shall not be less than 1.05 in ground effect for either of the above control applications.

Control Power. -At least 60 percent of the maximum control moment should be available about each axis when all controls are fully displaced.

Pure Lift Mode. -The aircraft should be designed for the composite propulsion mode (lift plus lift-cruise engines) with design provisions for later field conversion to the pure lift mode. Structural and service provisions should be provided for the pure lift mode.

Lift Engine Vectoring. -Vectoring of the engine exhaust shall be from 15 degrees ahead of vertical to 30 degrees behind vertical.

Wing Design-High Lift. -At least a 40 knot stall speed spread is required for the new aircraft, from 105 knots ±5 knots to 145 knots ±5 knots. The most feasible stall speed spread will be acceptable on the modified aircraft.

Design Limit Load Factors. -The new aircraft shall be designed to a limit load factor of 3.75g positive and 1.5g negative. The most feasible limit load factors resulting from the modified aircraft will be accepted.

Ground Loads. -The aircraft shall be designed for a limit VTOL sinking speed of 15 feet per second in combination with 2/3 hovering thrust at the VTO gross weight. For conventional landing, the limit sink speed shall be 12 feet per second with lift equal to weight at the VTO gross weight. For the modified aircraft, the requirement is to design to the most feasible sink speed.

METHODS OF AIRCRAFT EVALUATION

Both quantitative and qualitative factors were taken into account in the evaluation of design concepts. The primary performance measure was the ability of a concept to exceed 12.0 minutes hover endurance in the lift plus lift-cruise mode at 80°F, Sea Level. This capability was determined by the allowable VTO design gross weight of a concept with a given total number of engines when meeting the specified thrust-to-weight ratios and control requirements. An additional performance measure was in the corresponding hover endurance of the concept when converted to the pure lift mode.

Since all new designs incorporated the specified degree of lift engine exhaust vectoring, required load factor, and stall speeds, these factors were not considerations in the evaluation of new designs. However, in order to rate modified aircraft designs as well as to rate levels of hover endurance available and hover control margins of new aircraft designs, a qualitative utility rating method was established. This rating method was based on a 100 percent rating for an ideal aircraft which meets or exceeds all requirements specified. Rating percentages were established for vectoring angle limit, spread between maximum and minimum stall speeds, hover time, load factor, and control power, based on an evaluation of the proposed research program in terms of the percentage of research missions exceeding various levels of each of the above factors. The results of the rating showed Concept C to be the best of the new designs, primarily, because of its excellent hover time capability in both the lift plus lift-cruise and pure lift mode. The modified existing aircraft (Concept J) received a very low rating compared with the new aircraft, mainly because of the limited spread in stall speed between flaps up and down conditions.

A further operational factor rating scheme was applied to rate the various concepts in terms of their operational desirability (i.e., appropriate design features) for the proposed flight research program. In this case, score increments were allocated that added up to 100 for an ideal aircraft. The operational factor ratings for new aircraft designs were all fairly high, however, the rating for the Concept J modified aircraft was only about half that of the new aircraft.

The research utility and operational factor ratings are included in the comparison summary charts, Tables 8 and 14, respectively.

ENGINE CHARACTERISTICS

The engines selected for this study were limited to the General Electric YJ85-GE-19 engines for use as lift-cruise engines, and both the General Electric YJ85-GE-19 and Rolls Royce RB162-81 engines for use as lift engines. This selection was made primarily on the basis of availability and suitable thrust level. A comparison of the RB-162-81 and YJ85-GE-19 lift engines is shown in Table 1.

The basic engine data used to generate the installed performance was extracted from the General Electric Model Specification E1129 dated 1 November 1966 for the YJ85-GE-19 engine and the Rolls-Royce Preliminary Project Performance Report No. PP-183 dated December 1965 for the RB162-81 engine.

Performance computation for the YJ85-GE-19 engine was performed on the IBM 7094 using the General Electric supplied computer program No. PCJ066 whereas the computation for the RB162-81 engine was hand calculated in accordance with the method shown in Rolls Royce report No. PP-183.

TABLE 1. SUMMARY OF LIFT ENGINE CHARACTERISTICS

ENGINE	RB162-81	YJ85-GE-19
NET INST ENGINE THRUST (SL-80°F) - LB	4460 (13% BLEED)	2240 (10% BLEED)
CONTROL THRUST - LB	546	247
CONTROL THRUST PER SQ IN. DUCT	17.8	34.7
BLEED PRESSURE (PSIA)/TEMP (°F)	48/400	76/500
MIN HOVER SFC	1.32	1.08
ROTATING MASS INERTIA, I_p, LB FT^2/MAX. RPM	53.0/11400	16.7/16700
BARE ENGINE WEIGHT - LB	428	397
LENGTH - IN.	54.1	40.5
DIA OF INLET - IN.	23.4	16.1
MAX. DIA OF ENGINE - IN.	29.0	20.3
UNIT COST - DOLLARS	224,000*	60,000
MAX. CONTROL BLEED TIME LIMIT/BLEED %	1 SEC	CONTINUOUS/10%
MAX. EXHAUST GAS TEMP - °F	1765	1355
TIME BETWEEN OVERHAUL - HR	25	800

*DUTY NOT INCLUDED

CANDIDATE CONCEPTS

Preliminary Concept Comparisons

In Figure 1 is shown the three views of the seven concepts examined during Part I of the study. The aircraft are shown with one arrangement of J85 engines, Concepts A, B, C and E are new designs, and F, I and J are the modified aircraft. The number of lift engines were varied in each concept and the aircraft size, weight, inertia, and control capability determined for each configuration. In Table 2 is shown the matrix of engine arrangements studied. This represents a total of 34 different configurations. In addition, studies were made of the impact on aircraft size and capability of wing loading, aspect ratio, taper ratio, wing thickness, load factor, and the provisions for the pure lift mode. All of the new concepts had a midwing, low horizontal tail, wide track-long stroke gear, and satisfy the NASA requirements for visibility. The lift engines were canted at 15 degrees, where feasible, to accommodate the original NASA requirements of 45-degree aft to 15-degree forward vectoring. In the modified F-84F and the F-5B designs, clearance limitations of existing structure prevented canting of the lift engines.

TABLE 2. MATRIX OF ARRANGEMENTS - PART I

	Concept	Design	No. of Lift-Cruise	Total Number of Engines J85 L/C + J85 Lift			J85 L/C + RB162 Lift		
Intensive Study	B	New	4	8	9	10	6	7	8
	C	New	2	8	10	12	4	5	6
	F	F84 Mod	4	10	12	14	7	8	9
	J	T39 Mod	4	10	12	14	7	8	9
Less Intense Study	A	New	2	7	9		5	6	
	E	New	2	10			7		
	I	F5B Mod	4	8	10		6	8	

Concept A. - This new design has the lift engines mounted in the fuselage in a T-formation and two YJ85-GE-19 lift-cruise engines located in nacelles on top of the wing and against the fuselage side. Two diverter valves direct the lift-cruise exhaust through the trailing edge of the wing during the lift mode. The inlet of the lift-cruise engines are located behind the wing leading edge to minimize hot gas reingestion, and the exhausts are extended to clear the horizontal tail. This concept was too heavy and had high inertias, in comparison with the other new concepts; it required nine engines to provide adequate lift thrust and control margin. It was eliminated early in the Part II study.

Concept B. - This concept features four YJ85-GE-19 lift-cruise engines; two on top of the wing and two below, and a single row of lift engines in the fuselage. The two lift-cruise engines on top of the wing use diverter valves to direct the exhaust through the wing. The lower engines are fitted with rotating pipes that permit vectoring at any angle within a 90 degree range. The four lift-cruise engines provide two desirable features, high acceleration, and freedom from engine out problems in the cruise mode. In addition, the continuous vectoring of the lower lift-cruise engines adds flexibility to the transition operation. Further study was made of this design during Part II of the contract.

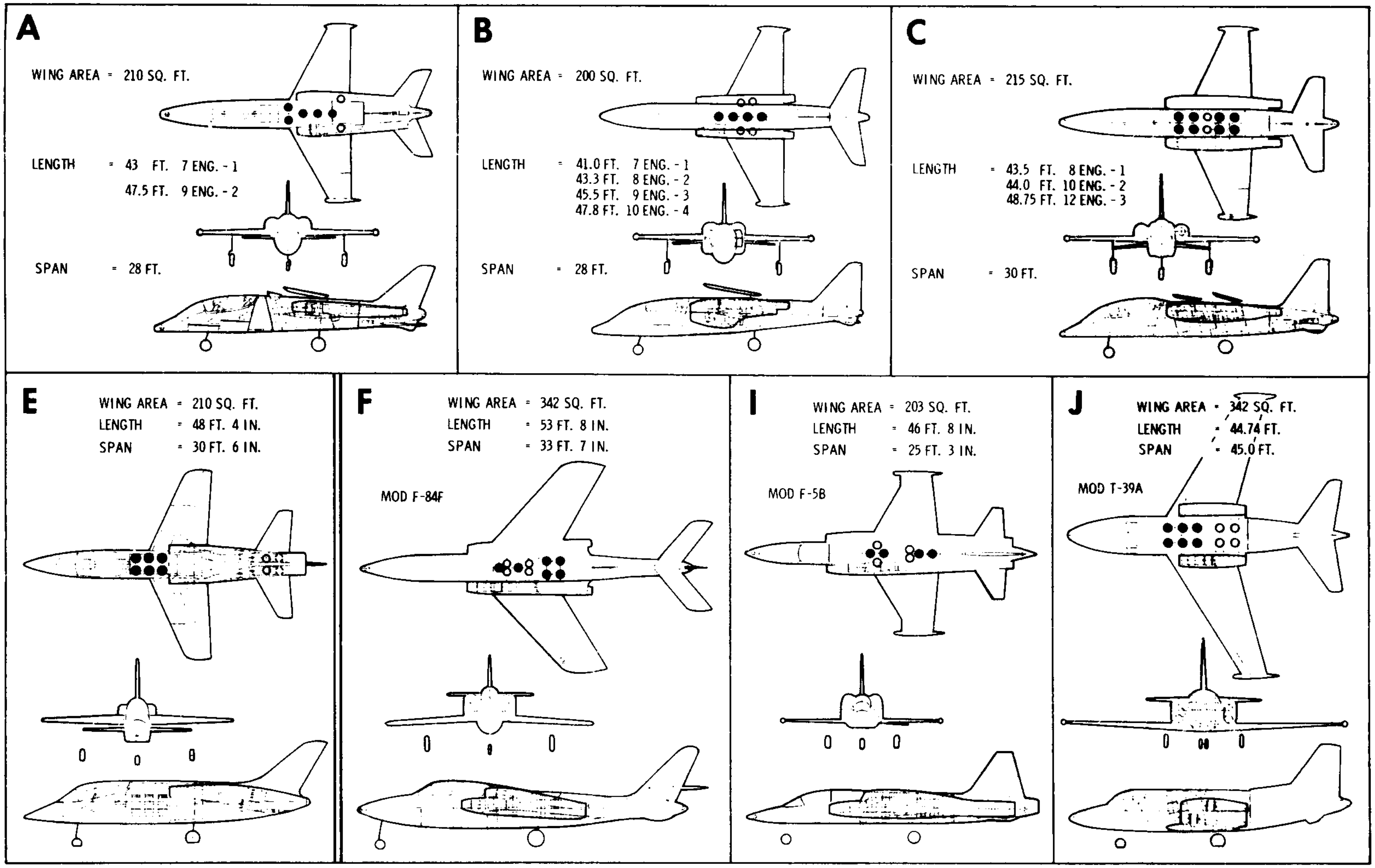

Figure 1. Baseline Concepts for Part I

Concept C. - This new concept has all the engines tightly packaged around the center of gravity. The YJ85-GE-19 lift engines are in two longitudinal rows in the fuselage and the lift-cruise engines are mounted in nacelles on top of the wing. The lift-cruise engine exhausts are diverted through the fuselage to provide a higher effective jet fineness ratio for the engine exhaust pattern. This serves to minimize hot gas re-ingestion and suckdown effects. The pure lift mode is conveniently obtained by replacing the lift-cruise diverter pipes in the fuselage with two additional lift engines. This design was the lightest of the new concepts and had the largest hover time in both the lift plus lift-cruise and pure lift modes of operation. Study of this configuration was continued during Part II of the contract.

Concept E. - This unusual and versatile new concept has ten YJ85-GE-19 engines installed, but is designed to hover with eight engines. The lift thrust arrangement is balanced with six lift engines mounted vertically in the forward fuselage and two of the four engines mounted in the aft fuselage. Two of the engines in the aft fuselage are fixed vectored lift engines. The remaining two are lift-cruise engines which are vectored through diverter valves. Inlets for these aft mounted engines are located over the wing at the 35 percent chord line. During either the lift plus lift-cruise or pure lift modes of operation.two of the four aft engines are on standby with an automatic feature to cut-in on failure of any aft mounted engine. The complexity of providing for engine failure plus the high response time of the backup engine eliminated this concept from further study.

Concept F. - This is a modified Republic F-84F airplane. The normal engine, inlet ducts, and tail pipe have been eliminated and the fuselage lengthened to provide a second cockpit. Lift engines are housed in a new section inserted at the existing fuselage splice. This design features four lift-cruise engines that are diverted through the fuselage to improve the lift engine exhausts fineness ratio. Although the design had the highest structural load capability of any concept, its size and weight required the use of twelve J85 engines which were considered to be excessive, and it was consequently eliminated from the study.

Concept I. - This is a modified Norair F-5B aircraft. Four lift engines have been installed in the fuselage and four J85 lift-cruise engines with diverter valves and curved tailpipes have been located in new nacelles on the upper surface of the wings. An entirely new fuselage section, aft of the cockpit, has been added to permit the installation of the engines and fuel tanks. A new wing leading edge with provisions for air ducting and control nozzles has been added. The landing gear has been strengthened and the back-up structure modified in order to accommodate the required speed loads. This concept was rejected because of the extensive structural changes required. In addition, at least ten YJ85-GE-19 engines are required to provide marginal lift thrust and control capability.

Concept J. - This is a modified North American T-39A airplane. The pod-mounted engines have been eliminated and the fuselage has been lengthened. A minimum of ten J85 engines, or a mix of three RB-162 lift engines plus four J85 lift-cruise engines, is required. The four lift-cruise engines have diverter valves and curved tailpipes, and are mounted within nacelles on each side of the fuselage above the wings. One fuel tank is located within the fuselage between the cluster of lift engines and the existing fuel cell aft of the former passenger compartment. The electronic payload package is in the aft fuselage. Heavier new main gears have been located further outboard on the wing in order to meet sink speed requirements and to clear the engine exhaust. This was the only modified aircraft concept that showed promise of providing the minimum required hover time of 12 minutes and satisfactory control with ten YJ85-GE-19 engines. It was consequently retained for further study during Part II of the contract.

Selected Candidate Concepts

At the beginning of Part II of the study, all of the baseline concepts were reexamined to determine the impact of the finalized NASA requirements. Following this evaluation only new Concepts B and C and the modified T-39A (Concept J) were retained for further comparisons. These concepts were all redesigned to incorporate the features found desirable as a result of the Part I studies. In Concept B, the upper lift-cruise engines were diverted into the fuselage, and the rotating nozzles of the lower lift-cruise engines were canted towards the fuselage center to obtain coalescence of the exhausts. The lift-cruise engines of Concept C were diverted into the fuselage ahead of the center of gravity to help modify the aircraft nose up pitch tendency during transition. This also permitted a side-by-side arrangement for all the YJ85 model lift engines. The reduction of the aft vectoring angle requirement from 45 degrees to 30 degrees permitted vertical installation of the lift engines in all the YJ85 arrangements in conjunction with the use of the Air Force ± 30 degree pivoting sphere nozzle. In the RB162 arrangement the lift engines were canted 7-1/2 degrees forward to simplify the development problem of providing additional travel on the Rolls Royce pivoting sphere nozzle (for an early RB162 version, the nozzle had ± 15° travel).

Concept J was redesigned for use of the North American stretched series-60 Sabreliner instead of stretching an existing T-39A aircraft. This approach was taken because of the negligible difference in program cost while gaining considerable reliability and minimizing the teardown and rework effort with new stretched Sabreliner components. The number of lift-cruise engines were reduced from four to two since a single YJ85 engine was found satisfactory for the single engine out criteria in the cruise mode. A new landing gear design was provided to increase the ground clearance and hence reduce the suckdown effects of the low wing and also to provide a longer stroke to meet the higher landing sink speed requirements.

At this point another new design, designated as Concept X was introduced into the study. This concept incorporated the rotating nozzle feature of Concept B but had only two lift-cruise engines, and maintained a compact engine arrangement(which is the outstanding feature of Concept C). The rotating nozzle is canted towards the fuselage at a 20 degree angle to obtain a high effective jet exhaust fineness ratio for the entire engine arrangement. Pure lift provisions are made by providing for the later addition of 2 cruise engines mounted in pods on top of the wing. Figure 2 shows comparative views of these remaining baseline concepts for one arrangement of both the YJ85-GE-19 and RB162-81 lift engines. The entire matrix of engine arrangements studied during Part II of the study is shown in Table 3.

TABLE 3. MATRIX OF ARRANGEMENTS - PART II

Concept	Design	No. of Lift Cruise	Total Number of Engines				
			J85 L/C + J85 Lift			J85 L/C + RB162 Lift	
B	New	4	8	9	10	7	8
C	New	2	8	-	10	-	6
X	New	2	8	9	10	5	6
J	Sabreliner Mod	2	10	12	-	5	

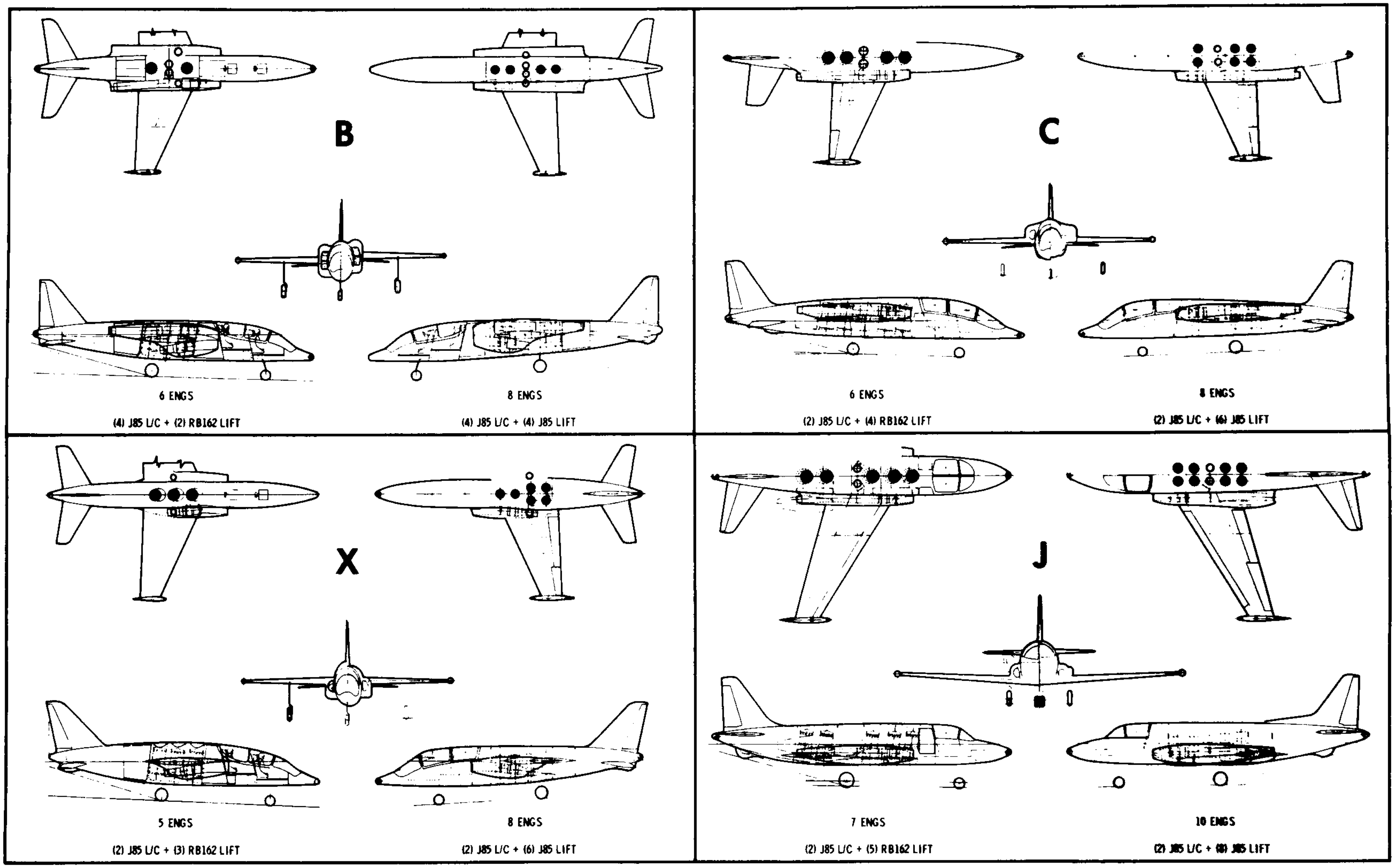

Figure 2. Baseline Concepts for Part II

CONCEPT CAPABILITIES EVALUATION

Aircraft Sizing for Hover Endurance

Each of the baseline concepts was examined on a parametric basis to determine the variation of hover time with VTO weight, and corresponding control capability. The results of this study are presented as Hover Time Design Charts in Figures 3, 4 and 5 for Concepts B, C and X respectively. The charts show, in their feasible region, the VTO weights and corresponding hover times of aircraft which meet the required thrust-to-weight ratios and attitude control requirements. Each point on any one engine arrangement curve represents a design corresponding to the parameters* indicated at the top of the figures.

For Concept B (Figure 3) only the ten YJ85-GE-19 engine design and the configuration with three RB162-81 lift engines result in design points with hover times reasonably greater than 12 minutes.

Concept C (Figure 4) has higher hover endurance than Concept B for corresponding engine arrangements and VTO weight. This is because Concept C has a higher permissible design VTO weight owing to better control margin with its shorter fuselage than Concept B. All three engine arrangements show feasible design regions above the minimum required hover time of 12 minutes. The maximum attainable hover time for the eight YJ85-GE-19 engine configuration is 14.3 minutes at a VTO weight of 15,500 pounds. The selected Concept C design point discussed later in this presentation was chosen prior to the finalization of this cut-off boundary, at a hover time of 14.0 minutes and a corresponding design VTO weight of 15,300 pounds.

In the case of Concept X (Figure 5), the eight-engine YJ85-GE-19 and the RB162-81 lift engine arrangements show higher hover times at corresponding engine arrangements and VTO weights than the other eight-engine concepts in the lift plus lift-cruise mode. This is primarily due to the tightly packaged engine arrangement available when no fuselage bay provisions are made for the pure-lift mode conversion. The pure-lift mode is obtained in this case by adding cruise engines in nacelles on top of the wing.

For a desired increment of hover endurance in all the new designs the RB162-81 configuration shows the highest rate of growth in VTO weight primarily due to the higher SFC's of this engine. No sizing chart is shown for Concept J since the aircraft has essentially fixed geometry.

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*W/S = Wing loading, lbs/sq.ft., A.R. = Wing aspect ratio,
N_z = Design limit (normal) load factor, T.R. = Wing taper ratio,
t/c = Wing average thickness-to-chord ratio.

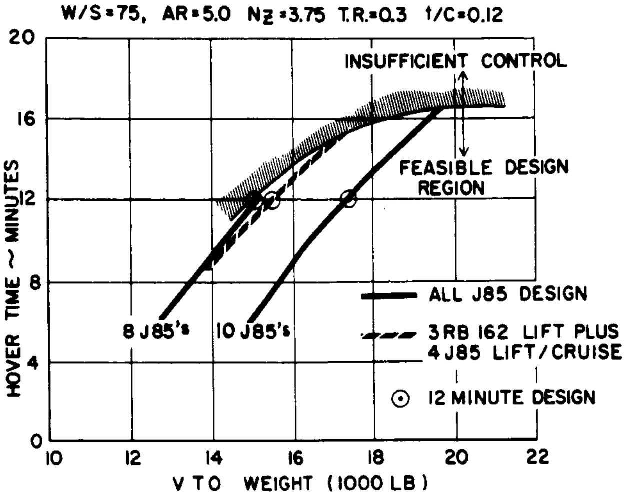


Figure 3. Hover Time Design Chart - Concept B

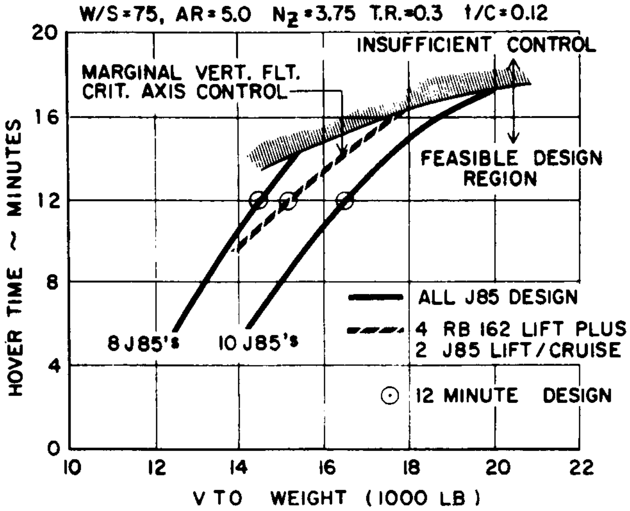


Figure 4. Hover Time Design Chart - Concept C

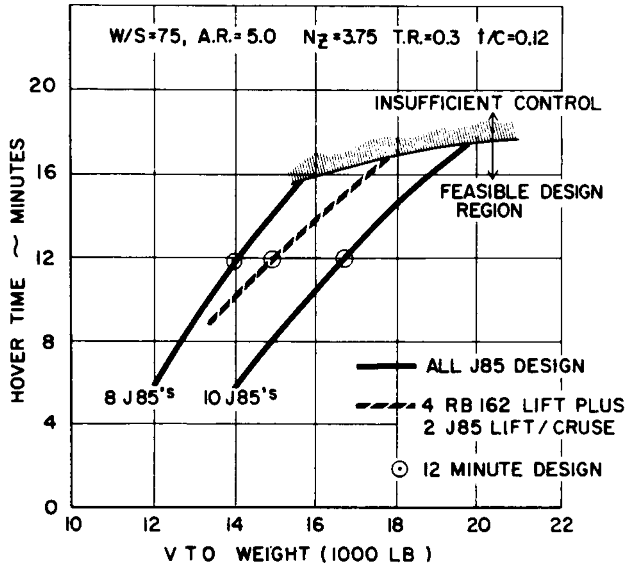


Figure 5. Hover Time Design Chart - Concept X

Control Requirements. -NASA normal control response requirements (item C, Table 4) are multiples of the AGARD Report 408 specification (item B) while damping characteristics are as per that specification. Hover control requirements (item D) were established at the end of Part I of the study as 60 percent of the maximum control power on all axes simultaneously.

For VTOL performance, the net lift thrust-to-design gross weight are specified at certain control power levels for simultaneous control usage on all axes (items E, F, G, and H).

TABLE 4. HOVER CONTROL REQUIREMENTS

Control Specification	Control (%)	Net Lift/Weight Ground Effects	
		In	Out
A. AGARD Emergency (single axis maximum)	†	-*	-*
B. AGARD Normal (single axis maximum)	†	-*	-*
C. NASA Normal (single axis maximum)	100** (reference values)	-*	-*
D. Hover	All axes, 60	1.0	1.0
E. Vertical Flight	All axes, 50	1.05	1.15
F. Vertical Flight, Critical Axis	Critical Axis, 80; others, 50	1.05	1.05
G. Single Engine Out	Roll Axis, 50; others, 20	-*	1.05
H. G, with additional reaction jet thrust to trim pitch and roll due to single engine failure			
J. Trim for 2% $\bar{c}$ c.g. deviation		-*	-*

* Values presented at lift/weight = 1.0
† Values specified in AGARD Report No. 408
** 2.0x AGARD roll response specification
1.5x AGARD pitch and yaw response specification
Damping = AGARD damping, all cases

In normal operation, either the hover case, or the vertical flight, critical axis case, requires maximum bleed air supply. In VTOL performance with a single engine failure, the net lift available is a critical consideration. The control margin between the control power required and the control power available is a measure of the maneuvering performance capability of the vehicle. The lift margin between the jet lift required and the jet lift available is a measure of the vertical performance capability of the vehicle. These control capabilities are shown in Table 5 for some of the concept configurations. The RB162-81 limit control bleed of 13 percent was assumed in these comparisons.

TABLE 5. CONTROL CAPABILITY OUT OF GROUND EFFECTS

Concept Configuration					Control Margin			Net Lift Margin		
	Engines			VTO Gross Weight Pounds						
		Lift								
Design	L/C	J85	RB 162		V. Flt. Crit.	Single Eng. Out + Trim	Hover	V. Flt. Crit.	Single Eng. Out. + Trim	Hover
B	4	4	-	15200	0	0	.03	.15	0	.20
	4	5	-	17500	.07	0	.43	.13	0	.18
	4	6	-	19790	.04	0	.07	.11	0	.17
	4	-	3	17400	.15	0	.16	.26	0	.33
	4	-	4	21900	.10	0	.13	.21	0	.27
C	2	6	-	15500	.11	0	.14	.15	0	.20
	2	8	-	20100	.10	0	.15	.11	0	.17
	2	-	4	17700	0	-.02	.04	.24	-.01	.31
J	2	8	-	19760	.05	.30	.05	.12	.01	.18
	2	-	5	19520	.21	-.06	.22	.37	.12	.45
X	2	6	-	15500	.15	0	.19	.15	0	.21
	2	8	-	19700	0	.36	.04	.13	.02	.19
	2	-	3	13170	.04	0	-.03	.35	0	.42
	2	-	4	17700	0	0	.03	.25	0	.32

$$\text{Margin} = \frac{\text{Available-Required}}{\text{Available}}$$

For each given gross weight and the corresponding moments of inertia, a control power analysis is performed for each concept configuration. The results are plotted in Figure 6, indicating the required control thrust as it varies with net lift thrust (or VTO weight) and control thrust available.

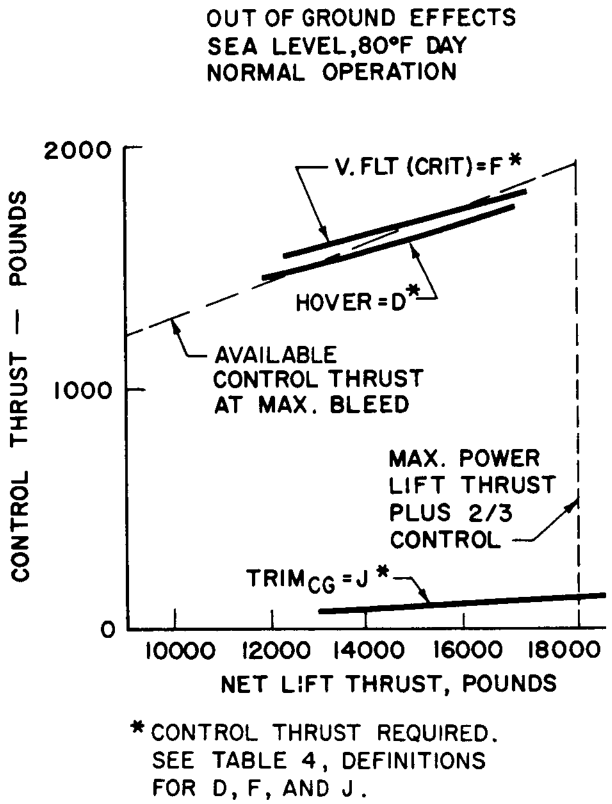


Figure 6. Sample Control Power Analysis

The net thrust available for lift at maximum throttle provides the lift limits of operation in vertical flight. The control system has the pitch and roll control jets in the down direction only, in the event of a single engine failure, additional lift is available from control jets. The actual lift augmentation obtained in this manner is dependent on the amount of thrust used for yaw control. Where no yaw control is being used, 100 percent of the control jet thrust will augment lift. As a general reference level, it was assumed that 2/3 of the total available reaction control thrust is used to augment the lift.

The installed thrust is reduced by hot gas reingestion and base losses around the vicinity of the jet exhausts. These two losses vary with height above the ground and the relative wind velocity and direction.

The net reaction jet thrust available for control at maximum compressor air bleed provides the total control thrust limits for operation in vertical flight. The control thrust varies with hot gas reingestion and engine power lever setting. The control jet thrust base loss is approximately constant whether the vehicle is in or out of ground effects due to the large ratios of height to reaction jet diameter.

A design weight is selected from the locus of control requirements such that the net lift margin is positive. The second criterion is that the control margin be positive. These two criteria are generally attained as shown in Table 5.

Relative Control Capabilities.-The relative control capabilities are considered for the 14 configurations in Table 5. The weights presented are approximately the maximum VTO design weights.

An increase in the number of engines does not necessarily improve the control margin at the maximum design weight. This is shown by Concept B with 4, 5, and 6 YJ85-GE-19 lift engines. This effect is also shown in the net lift margin, but is not as pronounced.

When RB162 lift engines are used in place of YJ85 lift engines, there is a much steeper fall-off in the control thrust available when lift thrust is reduced. This causes a deficiency in control at low fuel load conditions. Figure 7 presents the variation of control requirements with weight from VTO design weight to the zero fuel weight. Use of RB162 lift engines also results in higher emergency control requirements for coping with a single critical engine failure. It was therefore considered advisable to select the YJ85-GE-19 lift engine from the control capability standpoint.

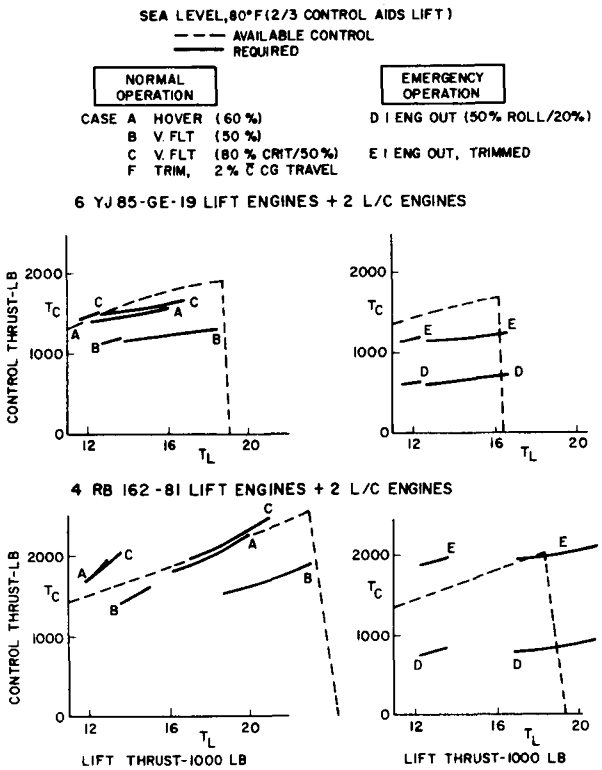


Figure 7. Hover Control Summary - The Effect of Lift Engine Type

Pure Lift Mode

Method of Modification. -The major changes necessary for conversion of the various concepts from a lift plus lift-cruise configuration to a pure-lift configuration are outlined in Table 6. The YJ85-GE-19 model engine is incorporated in all the cases shown.

Hover Endurance in Pure Lift Mode. -In Figure 8, hover time in the pure lift mode is used as a basis of comparison between the selected concepts for both the YJ85-GE-19 and RB162-81 lift engine models. The original configurations assumed to be converted to the pure lift mode, were sized for maximum hover time in the mixed mode (lift plus lift-cruise).

Where two YJ85-GE-19 or one RB162-81 lift engines are added to obtain the pure lift mode, it was assumed that the allowable VTO weight in the pure-lift mode would be equivalent to the basic lift plus lift-cruise aircraft VTO design weight. Concept B is an exception to this, since only one YJ85-GE-19 could be added for the pure lift conversion. In this case, the pure lift VTO weight was reduced by the net thrust of one engine.

TABLE 6. METHOD OF OBTAINING PURE LIFT MODE
(YJ85-GE-19 Engines)

Concept	Engine Arrangement		Method of Converting to Pure Lift Mode
	Basic L/C + Lift	Pure Lift Cr + Lift	
B	4 + 4	2 + 7	Delete upper L/C diverter and pipes in fuselage. Replace with 1 lift engine. Off-load fuel and 300 lb payload.
	4 + 6	2 + 9	Delete upper L/C diverter and pipes in fuselage. Replace with 1 lift engine. Off-load fuel and 300 lb payload.
C	2 + 6	2 + 8	Delete L/C diverter and pipes in fuselage. Replace with 2 lift engines. Off-load fuel and 300 lb payload.
	2 + 8	2 + 10	Delete L/C diverter and pipes in fuselage. Replace with 2 lift engines. Off-load fuel and 300 lb payload.
X	2 + 6	2 + 8	Add 2 cruise engines on top of wing in pods. Off-load fuel and 300 lb payload.
	2 + 8	2 + 10	Add 2 cruise engines on top of wing in pods. Off-load fuel and 300 lb payload.
J	2 + 8	2 + 10	Delete L/C diverter and pipes in fuselage. Replace with 2 lift engines. Off-load fuel and 300 lb payload.

The designs with the RB162-81 engines show up better in Concepts B, C, and X on the basis of the engine installation weight advantage. For example, in Concept C, for comparable installed thrust, the additional weight for the installation of two YJ85-GE-19 engines is 1020 pounds as against 640 pounds for one RB162-81 engine. However, the aircraft control capability for the RB162-81 configurations will be less than that for the YJ85, and the allowable VTO weight in the pure lift mode should therefore be reduced for the RB162-81 versions. The hovering performance indicated for the RB162 versions should thus be considered optimistic.

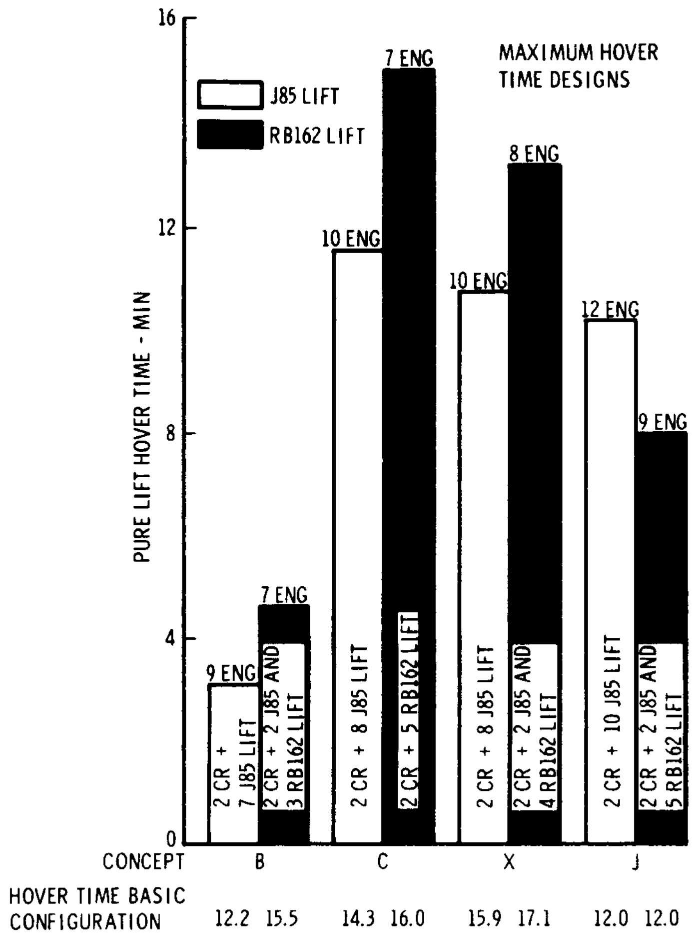


Figure 8. Pure Lift Hover Time Comparison

The pure-lift-mode conversion for the RB162-81 version of Concept J is obtained by adding the original Sabreliner cruise engines and nacelles and using the original YJ85 lift-cruise engines in the lift mode only. The weight of this conversion is heavier than that obtained by replacing the lift-cruise diverter pipes in the fuselage of the all-YJ85-GE-19 configuration, with two additional YJ85-GE-19 lift engines. This latter conversion results in a longer pure-lift hover time for the all-YJ85-GE-19 engine configuration than the RB162-81 version.

Concept C has the highest pure lift hover time of any new design. This is primarily due to the small weight penalty incurred in adding the two additional lift engines in place of the lift-cruise diverter pipes in the fuselage. In Concept X, on the other hand, there are no provisions in the fuselage for diverters, and the weight penalty incurred in adding two cruise engines to obtain the pure lift mode is much higher. Concept B shows the largest decrease in hover time, reflecting the fact that it can only accommodate one extra YJ85-GE-19 lift engine in the pure lift mode, which is one engine less than the other concepts can accept.

EFFECT OF LIFT ENGINE CHARACTERISTICS ON DESIGN

The lift engine characteristics affect the size and performance of the attitude control system, the amount of hover fuel required, the overall size and weight of the aircraft, and the aircraft cost and maintenance.

In Figure 9 is shown the effect on fuel consumption when RB162-81 engines are used. Approximately 23 percent more fuel is consumed by these engines than for the YJ85-GE-19 installations for the thrust outputs and design concepts shown. These plots were obtained by combining the lift engines with the lift-cruise engines at the same percentage of military thrust. The total thrust figures include 2/3 of the reaction control thrust available from the bleed air. The fuel flows have a 5 percent contingency added and correspond to control bleed of 5 percent for the YJ85 and 8 percent for the RB162-81 engine.

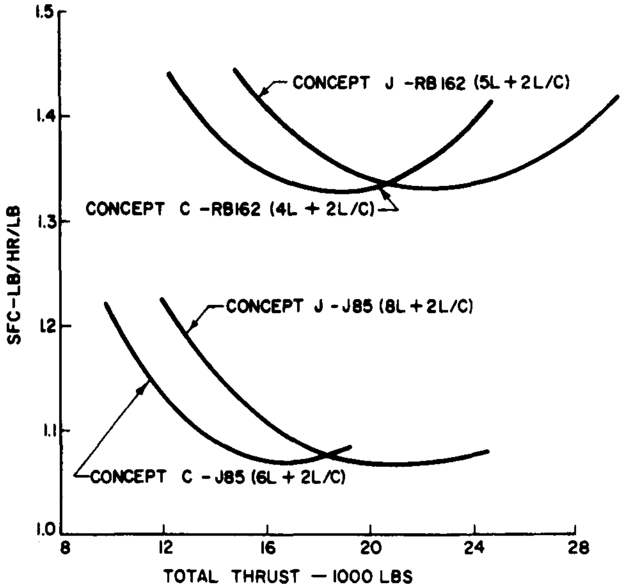


Figure 9. Engine Installation S. F. C. Data

An important impact on design is indicated in Figure 10 where a comparison of the control thrust available for both YJ85-GE-19 and RB162-81 lift engine installations is presented. The use of the RB162-81 lift engine in this instance results in a much lower control thrust output on a continuous basis (due to a 8 percent continuous bleed operation limit as opposed to a 10 percent limit for the YJ85-GE-19) and requires bleed duct sizes of approximately twice the area because of lower bleed pressure.

For Concept C, Figure 11shows the effect of the engines on the aircraft size and weight, and the corresponding moments of inertia. In this figure, Design (1) represents the configuration using YJ85-GE-19 lift engines, while Design (2) represents the configuration incorporating the RB162-81 engines. As shown by the trace of the broken line, the RB162-81 lift engine airplane is heavier and greater in span and length and, as a consequence, is shown to have larger moments of inertia.

The YJ85 configuration is consistently lighter than the RB162 configuration for all new designs, whereas for the modified aircraft the reverse is true. This is illustrated for Concept J in Figure 12. In the new configurations the YJ85 installation results in a more compact aircraft, whereas in the modified aircraft where the aircraft is of fixed size for both engine installations, the difference in weight is primarily due to the lignter RB162 propulsion. The impact of the lighter RB162 propulsion in both the new and modified designs is offset by its higher fuel requirements.

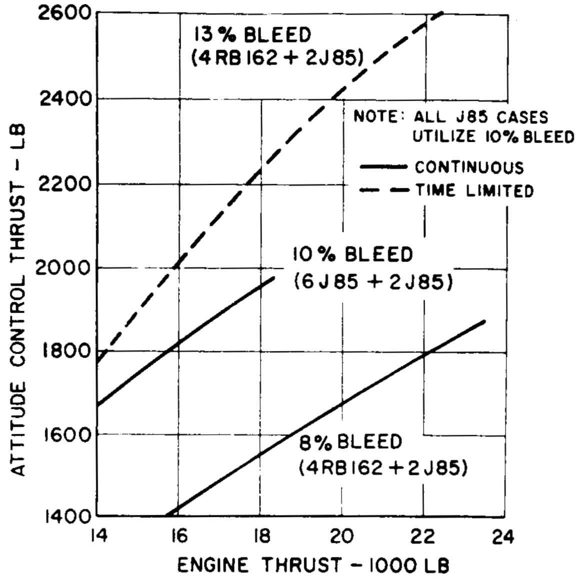


Figure 10. Engine Installation, Control Thrust Data

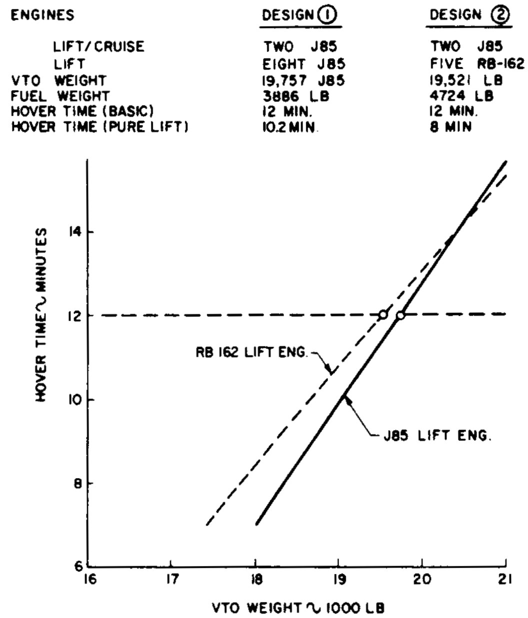


Figure 12. The Effect of Lift Engine Type on Hover Endurance for Concept J

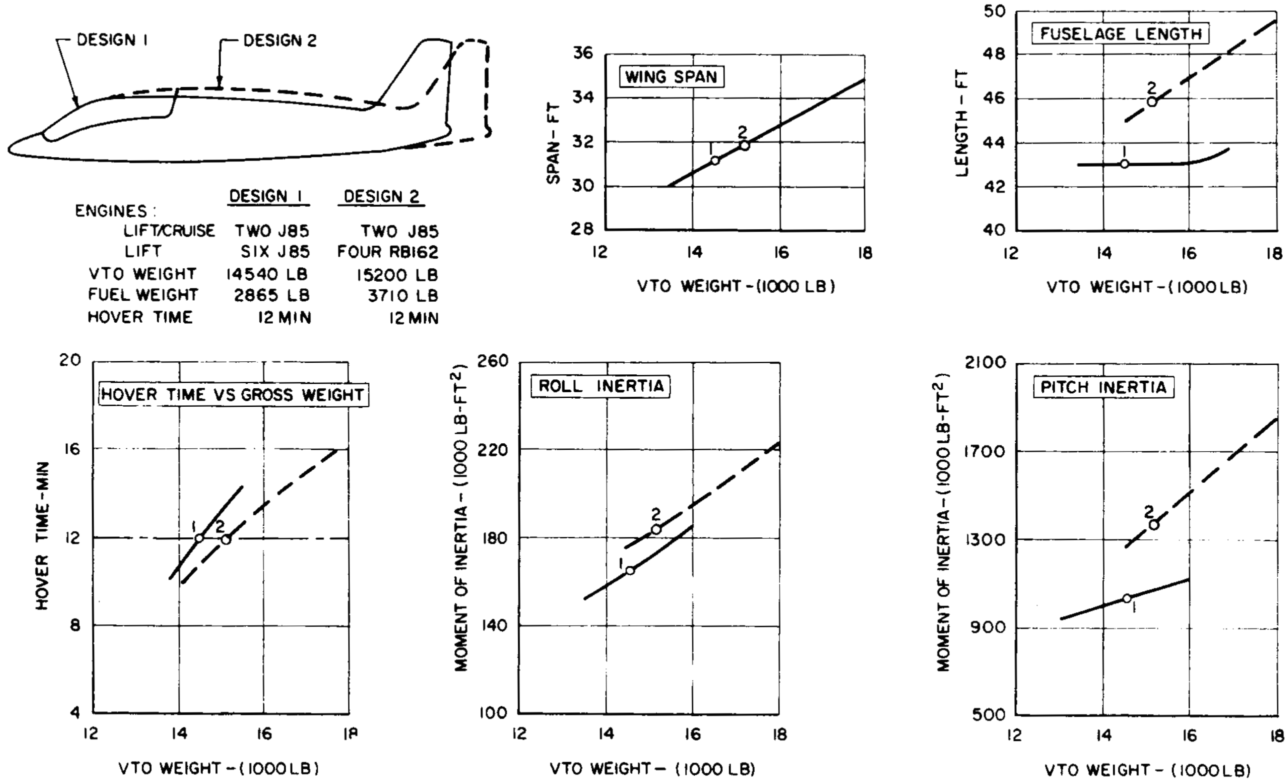


Figure 11. Comparison of Two Lift Engine Configurations - Concept C

Selection of Lift Engine Type

The results of the Part II comparative studies have shown that the YJ85-GE-19 engine has a decided advantage over the RB162-81 lift engine for the basic research mission. Use of the GE - YJ85-GE-19 lift engine results in the following advantages:

1) reduced aircraft moments of inertia
2) a smaller and shallower fuselage
3) reduced fuel requirements
4) less trim control required in the event of an engine failure
5) smaller reaction control ducts
6) lower exhaust temperatures
7) longer time between overhaul
8) maintenance and ground support of only one engine model
9) permits easier engine removal
10) provides better ground clearance
11) smaller gyroscopic disturbance moments
12) increased control margin available when hovering at reduced gross weight
13) reduced program cost

In addition, pivoting sphere nozzles for vectoring are presently under development for the YJ85-GE-19 engine by the General Electric Company under USAF funding. The RB162-81 lift engine, however, requires the design and development of a spherical nozzle in conjunction with Rolls-Royce by the NASA, or an airframe contractor.

The General Electric Company YJ85-GE-19 engine was selected, therefore, for use in detailing Concepts C and J.

CONCEPT COMPARISON SUMMARY

Comparison of Maximum Hover Time Designs

The VTO weight, hover time and fuel capacity of the maximum feasible design points obtained from the aircraft parametric sizing procedure are summarized in Table 7 for all the selected baseline concepts. The hover control margins for these design points have been shown previously in Table 5.

TABLE 7. CONCEPT CHARACTERISTICS SUMMARY FOR MAXIMUM HOVERTIME DESIGNS

Concept	Item	J85 Lift Engines				RB162 Lift Engines			
		Basic	Pure Lift	Basic	Pure Lift	Basic	Pure Lift	Basic	Pure Lift
B	Total Engines	8	9+	10	11+	7	7	8	9+
	L/C or Cr.	4	2	4	2	4	2	4	2
	VTO Weight	15,200	12.900	19,790	17,500	17,400	13,400	21,900	21,900
	Fuel	3115	815	5100	2812	4960	1450	7076	6966
	Hover Time	12.2	3.2	16.4	8.8	15.5	4.6	17.7	16.5
C	Total Engines	8	10✚	10	12✚	6	7+		
	L/C or Cr.	2	2	2	2	2	2		
	VTO Weight	15,500	15,500	20,100	20,100	17,700	17,700		
	Fuel	3540	3170	5400	5030	5380	5390		
	Hover Time	14.3	11.6	17.3	14.8	16.0	15.0		
X	Total Engines	8	10*	10	12*	5	7*	6	8*
	L/C or Cr.	2	2	2	2	2	2	2	2
	VTO Weight	15,500	15,500	19,700	19,700	13,170	13,170	17,700	17,700
	Fuel	3800	2930	5490	4620	3211	2341	5672	4802
	Hover Time	15.9	10.8	17.9	13.9	12.6	8.1	17.1	13.2
J	Total Engines			10	12*	7	9*		
	L/C or Cr.			2	2	2	2		
	VTO Weight			19,760	19,760	19,520	19,520		
	Fuel			3890	2574	4724	3408		
	Hover Time			12.0	10.2	12.0	8.0		

\+ 1 lift engine added for pure lift mode
✚ 2 lift engines added for pure lift mode
* 2 cruise engines added for pure lift mode

VTO Weight in pounds
Fuel in pounds
Hover Time in minutes

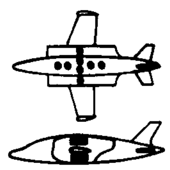
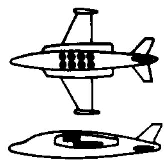
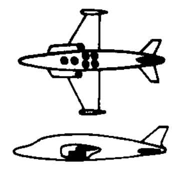
New Concept Comparison. - Concepts C and X are approximately the same length. The small additional length of Concept C is due to the engine bay arrangement which includes provisions for the pure-lift mode configuration. Concept B is longer because it uses a single row engine arrangement.

The lift engines are tightly packaged about the airplane center of gravity in Concepts C and X but spread out more in Concept B. Provisions are made in Concept C for conversion to a pure-lift mode without external changes to the aircraft. This is also true of Concept B except that it is limited to only one additional lift engine and therefore has marginal hover endurance in the pure lift mode. Concept X requires external modification for addition of two cruise engine nacelles on the wing in converting to the pure lift mode configuration.

A rotating nozzle allows continuous lift-cruise engine thrust vectoring during transition flight of Concepts B and X. This rotating tail pipe requires developmental effort. The Concept C lift-cruise engines can only divert from cruise to lift mode. Its diverter design has been developed and proven.

The differential program cost and the research utility rating favor selection of Concept C whereas the operational factor is better for Concept X. Table 8 summarizes the principal features of the concepts on a side-by-side basis.

TABLE 8. COMPARISON OF NEW CONCEPTS
(Eight YJ85-GE-19 Engines)

CONCEPT	B 	C 	X 
SIZE			
WEIGHT	15,200 LB	15,500 LB	15,500 LB
LENGTH	46.0 FT	43.0 FT	40.4 FT
SPAN	31.9 FT	32.2 FT	32.2 FT
ENGINES			
LIFT/CRUISE	4	2	2
LIFT	4	6	6
LIFT/CRUISE VECTORING	CONTINUOUS VECTORING (0° TO 90°)	DIVERTER *	CONTINUOUS VECTORING (0° TO 90°)
PURE LIFT MODE	PROVISIONS ARE IN FUSELAGE FOR ONE LIFT ENGINE	PROVISIONS ARE IN FUSELAGE FOR TWO LIFT ENGINES	NEW WING PODS REQUIRED FOR TWO CRUISE ENGINES
HOVER TIME			
BASIC	12.2 MIN	14.3 MIN	15.9 MIN
PURE LIFT	3.2 MIN	11.6 MIN	10.8 MIN
NET LIFT/WEIGHT	1.27	1.26	1.26
THRUST LOADING (T/W IN CRUISE)	0.58	0.28	0.28
PROBLEM ITEMS	POSSIBLE REINGESTION		POSSIBLE REINGESTION
DEVELOPMENT ITEMS	ROTATING NOZZLE		ROTATING NOZZLE
DIFFERENTIAL PROGRAM COST, $	+ 0.84 MILLION	DATUM	+ 0.18 MILLION
RESEARCH UTILITY RATING	4	46	36
OPERATIONAL FACTOR	71	79	87

Note: All lift engines have spherical nozzles capable of -15 to +30 degree vectoring.

* Spherical nozzle added to lift mode for -15 to +30 degree vectoring capability

Selection of One New Concept. - Concept C was selected as the best all-around design. Its principal advantages over the other new concepts under consideration are evident in 1) better hover time, 2) good growth capability, 3) a pure-lift configuration resulting in the highest pure-lift mode hover time, 4) minimum reingestion, 5) least development requirements, 6) satisfactory conventional performance, 7) lowest program cost of the new designs, and 8) a less complex lift-cruise engine management than Concept B.

Comparison Views of New and Modified Aircraft

The elevation views of Concepts C and J are presented in Figure 13. The increased visibility afforded to a pilot in Concept C can be noted in the canopy design. An additional point of difference is in the midwing configuration for Concept C in contrast to a low-wing in Concept J.

The perspective views of Concepts C and J are presented in Figure 14. The louvers on the lift engine doors permit greater pressure recovery to be obtained during vertical flight modes. The dimensions and general data for these aircraft are shown in Table 9.

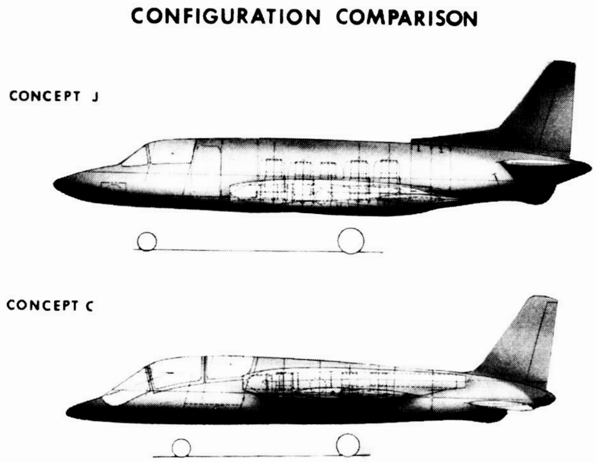


Figure 13. Configuration Comparison - Relative Elevation Views

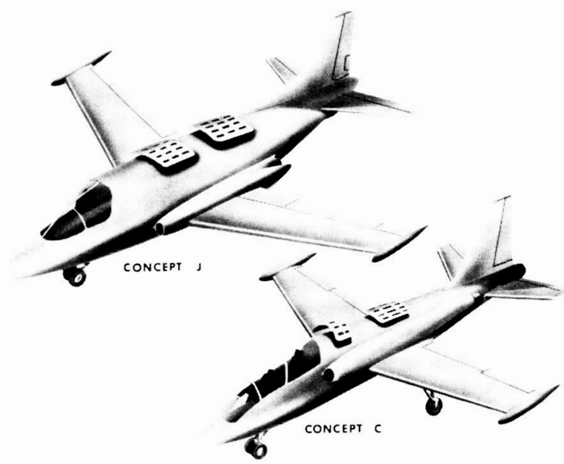


Figure 14. Configuration Comparison - Relative Perspective Views

TABLE 9. DIMENSIONS AND GENERAL DATA-CONCEPTS C AND J

	Concept C	Concept J
Ramp Weight (lb)	15,570	20,081
VTO Design Gross Weight (lb)	15,300	19,757
Hover Time (min)	14	12
Maximum Fuel Weight (lb)	3,710	4,210
Wing Data:		
Wing Area (ft^2)	204	342
Root Chord (in.)	117.5	139.9
Tip Chord (in.)	35.2	44.9
Theoretical Wing Span (ft)	32.0	44.6
Aspect Ratio	5.0	5.8
Taper Ratio	0.3	0.3
Wing Profile	NACA 64A (Mod)	NACA 64A (Mod)
Thickness Ratio at Root (%)	12.0(*)	11.3
Thickness Ratio at Tip (%)	18.0	9.4
Leading Edge Sweepback (deg)	25.0	32.0
Mean Aerodynamic Chord (in.)	83.75	100.6
Dihedral Angle (deg)	0	3.0
Vertical Tail Area (ft^2)	36.0	41.6
Horizontal Stabilizer Area (ft^2)	65.5	77.0

(*Constant to 70 percent semi-span)

Preliminary Design of a New Concept

General Arrangement - Concept C. - This concept (Figure 15) has a compact lift engine arrangement. Two YJ85-GE-19 lift-cruise engines are located against each side of the fuselage over the wing with the diverted lift thrust exists in the fuselage. Six YJ85-GE-19 lift engines are located in two rows in the fuselage with two forward and four aft of the diverter pipes so that the thrust is balanced about the c.g. of the airplane.

For the pure lift mode of operation, the exhaust diverter-curved tailpipe system is removed and replaced by two additional lift engines.

Tandem cockpits provide good visibility. Two fuel tanks are located in the fuselage, one forward and one aft of the clustered engines. The air conditioning unit is located forward of the cockpits. The electronic payload equipment is located in the aft fuselage and is highly accessible.

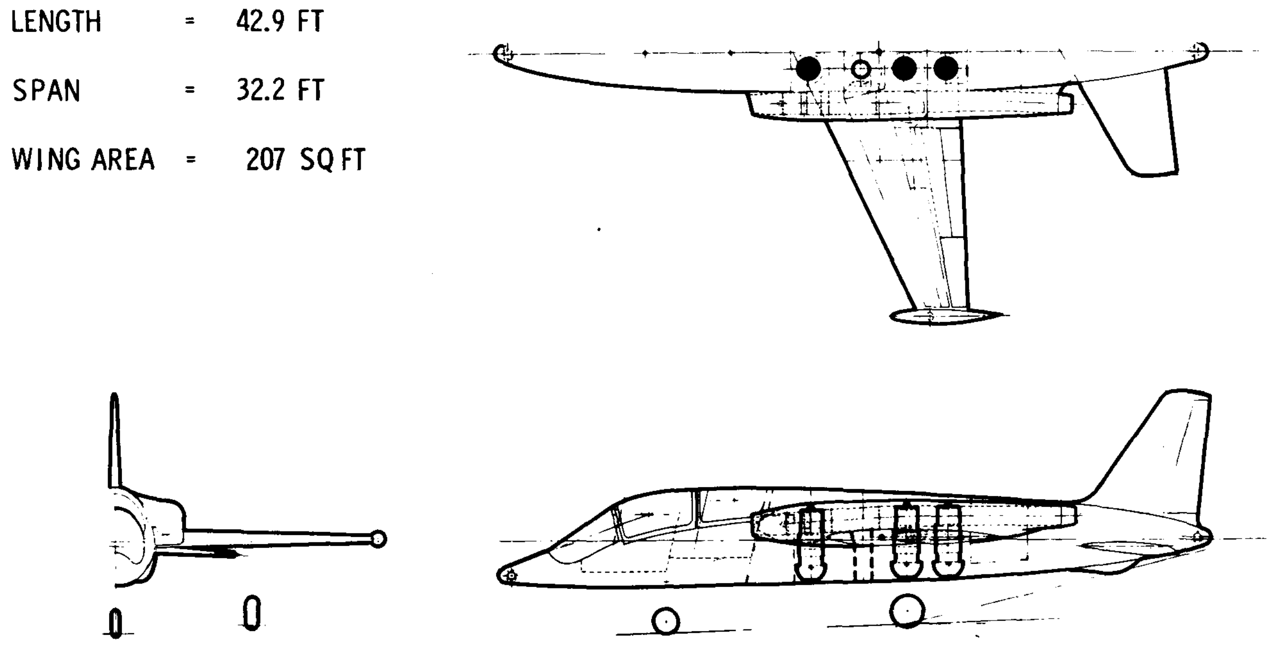


Figure 15. General Arrangement - Concept C

Inboard Profile - Concept C. - Each pilot has an individual canopy to provide good ingress and egress to the cockpit, and the cockpits are equipped with safe, fast-operation, zero altitude, zero velocity, ejection seats (Figure 16).

The attitude control system has valves to modulate compressor bleed thrust at the nose, tail, and wing tips. Removable nose, tail, and wing tip pods will provide access to these valves.

Each lift engine is located in a separate compartment and can be removed and installed from the bottom of the airplane when the landing gear struts are pressurized to the fully extended position. Spherical nozzles for thrust vectoring are operated by the airplane hydraulic system

Access is provided to the bottom half of the lift engine through twin doors that open outwardly when the lift engines are in operation. Structural doors are provided alongside the engine air inlets to provide access to the top half of the lift engines.

The nacelle engines are located so that the accessory section is forward of the front spar, providing easy access.

Two inlet doors are provided for the lift engines so that ram air start can be obtained. This ram is supplemented by compressor bleed from the lift-cruise engines. All engines will start from an air ground cart.

The electronics compartment is located aft, and communications equipment is mounted directly on the access door. As the equipment opens with the door, space is provided for access to the bottom and ends of the computers and the power supply units. Space is available and accessible in the compartment at the aft end of the door for additional equipment.

Two access doors are provided on each side of the fuselage next to the computers to provide maximum access to their outboard sides. This permits additional units to be mounted around and on these doors. The computers and power supplies are removable through the large access door at the bottom.

Structural Diagram - Concept C. - The structure is of conventional design with emphasis on ease of construction and maintenance. (Figure 17) The fuselage forward section has typical cockpit longerons, lower longerons, floors, and frames. The nose-gear trunnion is located at the bulkhead aft of the safety pilot and between two longitudinal beams in the nose-gear compartment. The center section has three longitudinal beams which serve as the side walls of the lift-engine compartments and also provide the supporting structure for the main engine mounts. Bulkheads separate the engines and fuel tanks and provide supporting structure for the rear stabilizing mount on the lift engines. The caps of the side beams serve as the upper and lower longerons, giving continuity with the forward and aft fuselage. The housing for the lift-cruise engines is integral with the fuselage and contributes to the primary structure of the aircraft. The aft fuselage has upper and lower longerons and several primary frames which provide for mounting the empennage.

The stabilator is supported on a torque tube extending through the fuselage. The design will permit removal of either side of the stabilator without disconnecting the actuators or controls. The vertical tail is mounted on two primary frames, and the design will permit easy removal.

The wing structure consists of two primary spars forming a box with stiffened skins. The spars pick up two bulkheads in the fuselage and become integral with that structure. An auxiliary spar provides a means for attachment of flap and aileron hinges as well as an aft support point for the main-landing-gear trunnion. The forward support for the trunnion is in the main box. A splice, for convenience of shipping, is located outboard of the landing gear support rib.

1 COMPUTERS - 2 REQD.
2 POWER SUPPLY - 2 REQD.
3 VHF TRANSCEIVER
4 GYRO COMPASS
5 ATC TRANSPONDER
6 DOPPLER ANTENNA
7 DOPPLER SIGNAL CONVERTER
8 RADAR ALTIMETER
9 VERTICAL GYRO
10 MARKER BEACON
11 DME-DISTANCE MEASURING EQUIP.
12 VOR/ILS - RECEIVER
13 AIR CONDITIONING UNIT
14 DIVERTER VALVE - 2 REQD.
15 SPHERICAL NOZZLE - 6 REQD.
16 J85 LIFT CRUISE ENGINE - 2 REQD.
17 J85 LIFT ENGINE - 6 REQD.

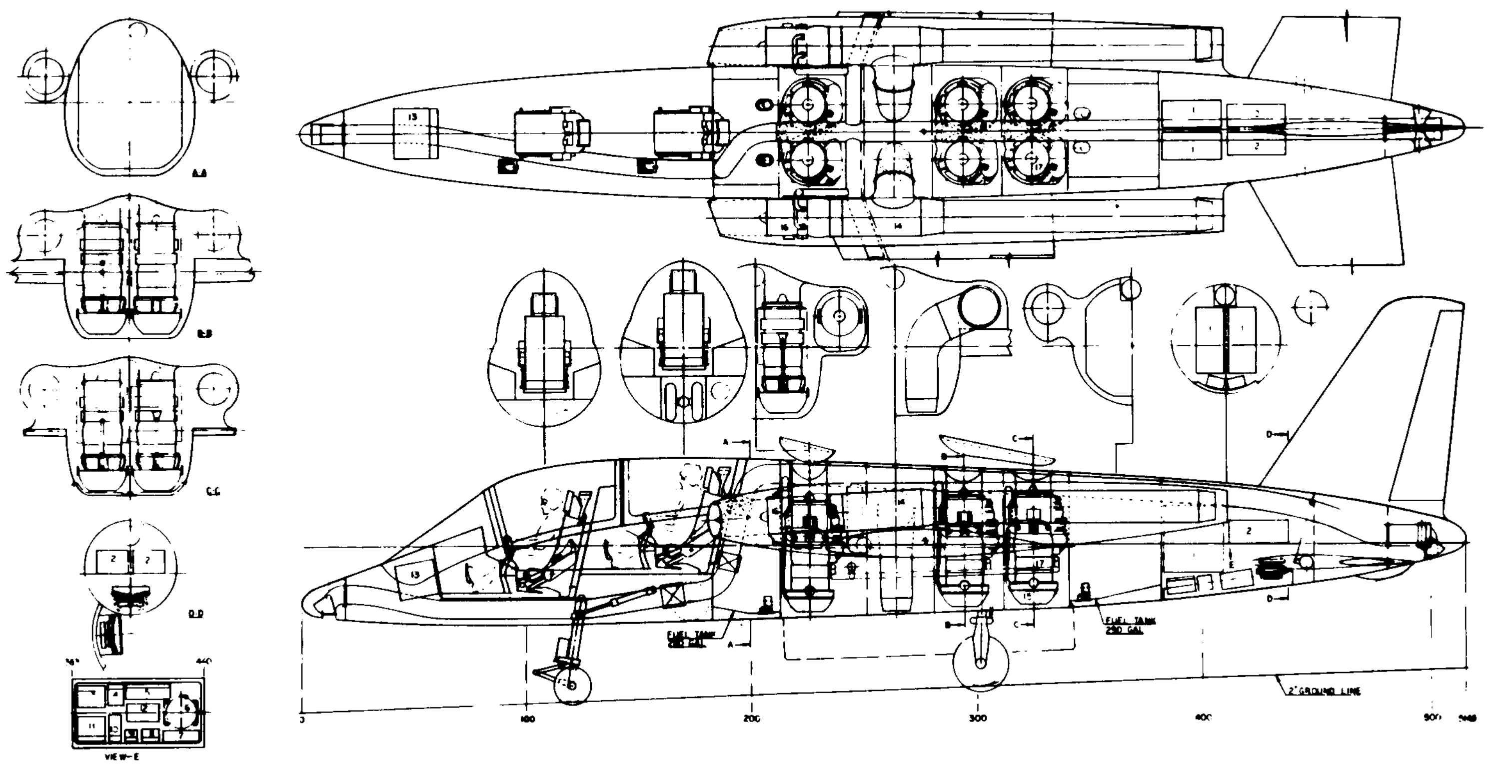


Figure 16. Inboard Profile - Concept C

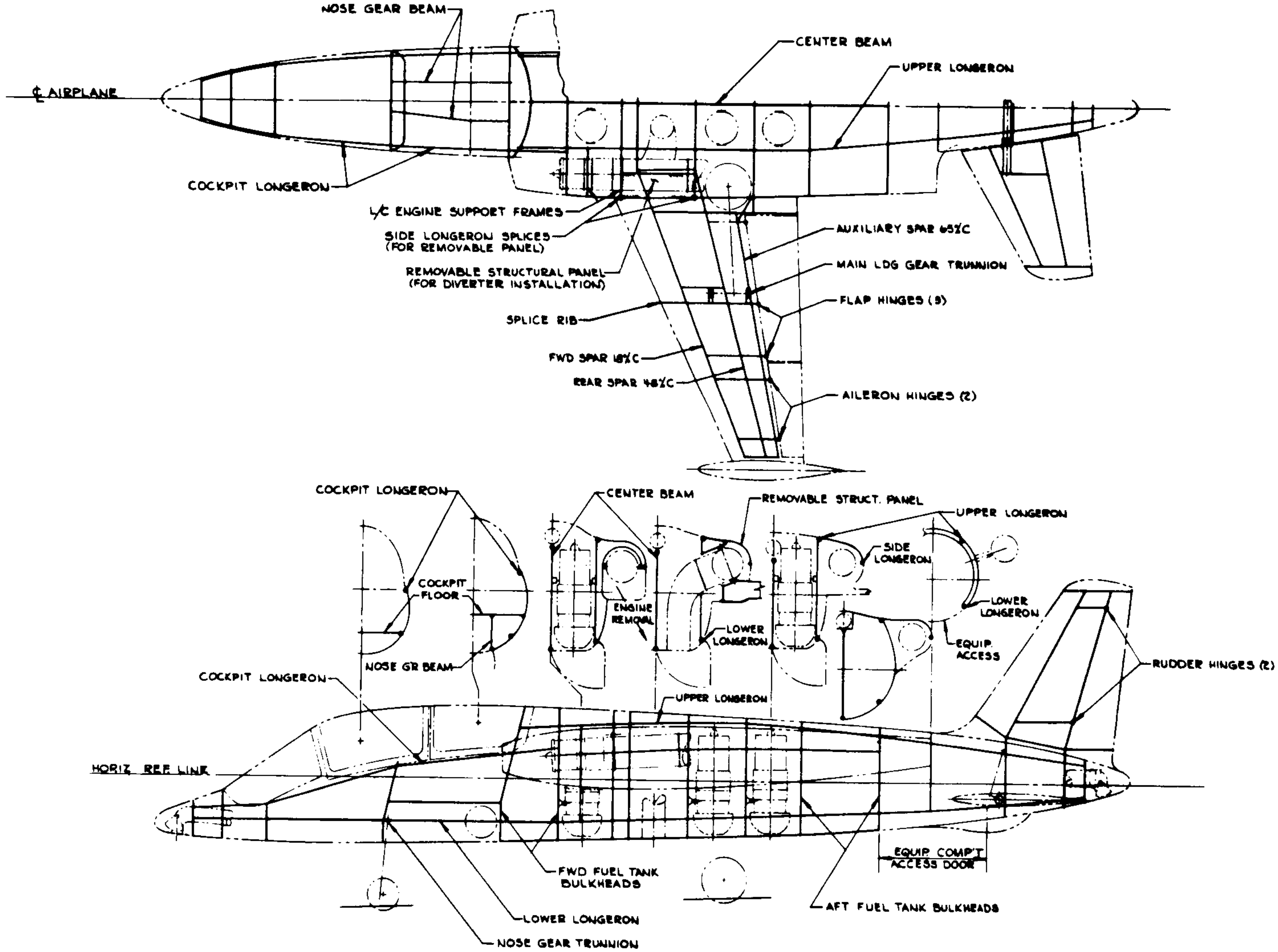


Figure 17. Structural Diagram - Concept C

Preliminary Design of a Modified Concept

General Arrangement - Concept J. - In Figure 18 is shown a modified North American stretched Sabreliner. The pod-mounted engines have been eliminated. Two YJ85-GE-19 lift-cruise engines are mounted within nacelles on each side of the fuselage and over the wing. Diverter valves connect to exhaust pipes located in the fuselage about the airplane c.g. Eight YJ85-GE-19 lift engines are mounted vertically in two rows in the fuselage equally spaced about and close to the airplane c.g. Two additional YJ85-GE-19 lift engines can be installed in place of the diverter exhaust pipes, allowing the engines in the nacelles to be used only for cruise when converting to the pure lift mode.

The cockpit and canopy are redesigned to provide for zero-zero ejection and better visibility and to reduce weight. Entrance doors to the cockpit have been eliminated, and access is provided through hinged canopies. New main and nose landing gear are required with the main gear retracting aft into the nacelles.

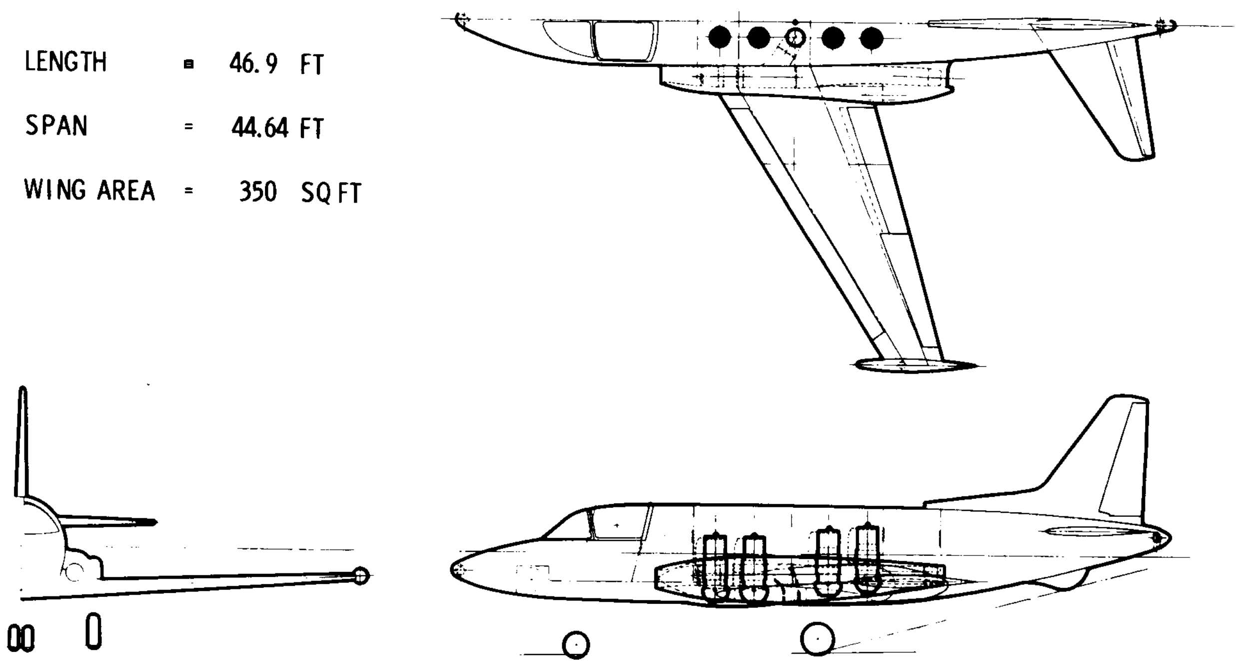


Figure 18. General Arrangement - Concept J

Inboard Profile - Concept J. - The cockpit section is redesigned to provide for installation of zero-zero ejection seats. A new windshield and hinged canopies are required for pilot entrance and egress. The Sabreliner fuselage geometry limits the visibility and positions the pilots too closely together for optimum ejection paths. Due to the limited space available, the locations of the required cockpit equipment are poor. (Figure 19)

The midsection of the fuselage has to be redesigned for installation of the ten lift engines with ducting and access, inlets, and exit doors. Bays are provided forward and aft of the engines for installation of fuel tanks. The cruise engine nacelles are attached to the side of the fuselage and on top of the wing.

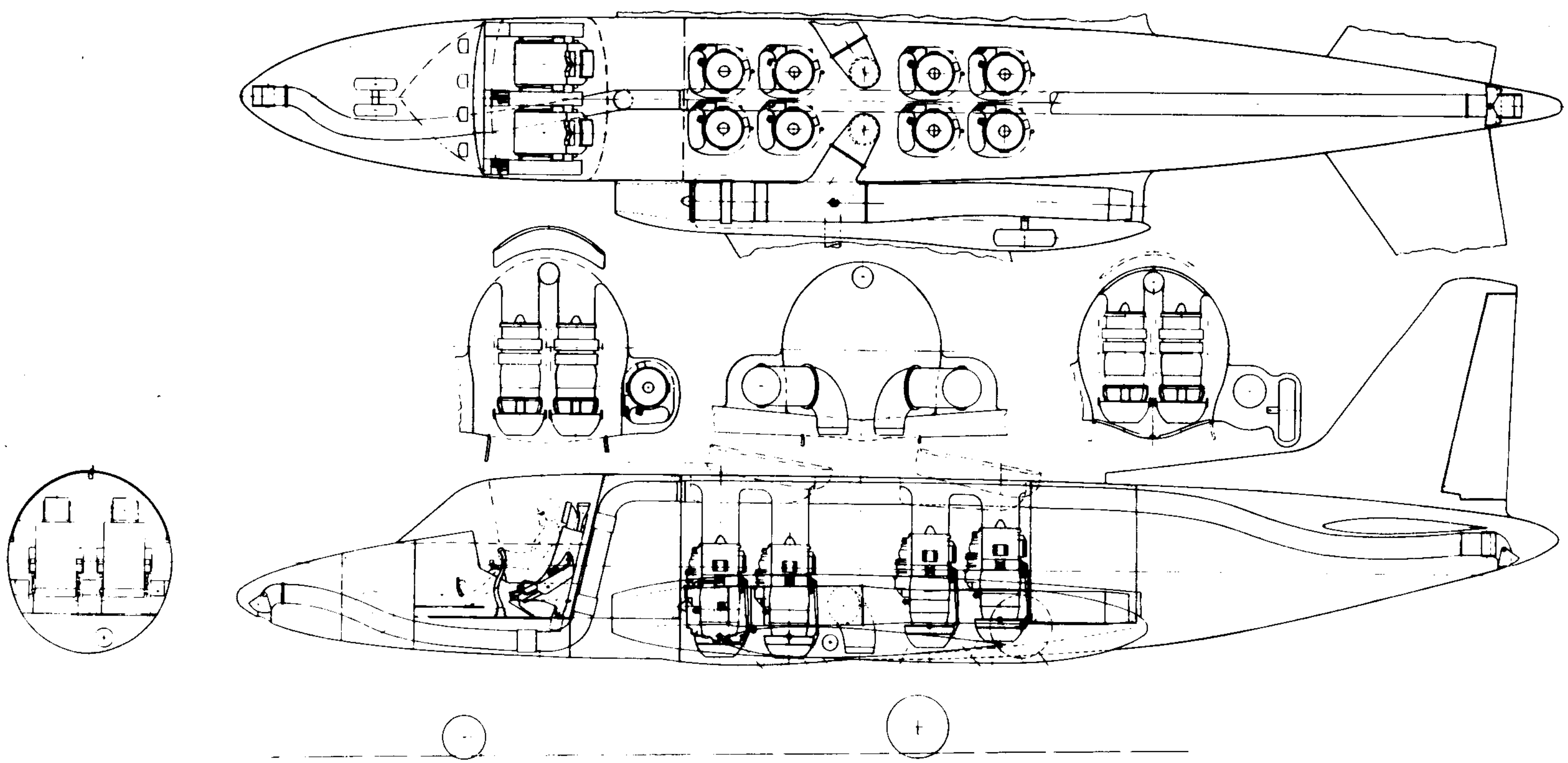


Figure 19. Inboard Profile - Concept J

The nose and tail section of the fuselage will be modified for hovering controls installation. A new wheel well and new attachment fittings will be required for the nose landing gear.

The wing center section across the fuselage and the section under the nacelle will be redesigned. The attachment fittings for the main landing gear also requires redesign. The attitude control ducting will be routed through the entire span of the wing, and jet nozzles will be installed in pods at the wing tips.

New longer shock struts and retracting mechanism with shrinkage struts are required for the nose and main landing gear. A new wheel well for the main gear will be faired into the cruise engine nacelle.

The ducting and nozzles for hovering controls will be installed in the fuselage and wing, and the ducting will be manifolded to engine air bleed outlets. Revision and rerouting of the present Sabreliner surface controls will be required.

Structural Diagram - Concept J. - In Figure 20 is shown the major structural members for the modified North American stretched series-60 Sabreliner. The modification consists of removing the fuselage pod-mounted engines and extensively reworking the fuselage and wing structure.

The nosewheel well structure must be reworked to accommodate the longer nose gear and the trunnion support structure must be reinforced to meet the higher sink speed requirements. Hover control ducting and nozzles also will require rework to the existing structure.

Extensive rework will be required in the cockpit section to add a new cockpit enclosure (windshield and canopy). The cockpit floor will be redesigned to provide for the two zero-zero ejection seats, floor-mounted control stick and rudder pedals, and new pedestals and consoles.

In the fuselage center section, extensive rework will be required to replace the entrance door, windows, bailout and ground emergency hatches, speed brakes, main landing gear wheel wells, and engine pods and to add the new center and outboard beams, upper and lower longerons, inlet and exhaust ducts and doors, engine support structure, and forward and aft fuel compartments.

The aft section will need rework to add ducting and nozzles for hover control, tail bumper and rearrangement of equipment in the equipment compartment.

Extensive rework will be required to the top and bottom wing box covers, ribs, and front and rear spars to provide for the support and ducting for the lift and cruise engines and nacelles. Additional ribs will be required. Ducting and nozzles for hover control and a new wing tip will require additional rework. The main landing gear trunnion and support structure will be reworked to provide for the higher sink speed requirements and the rearward retraction of the main landing gear into the nacelles.

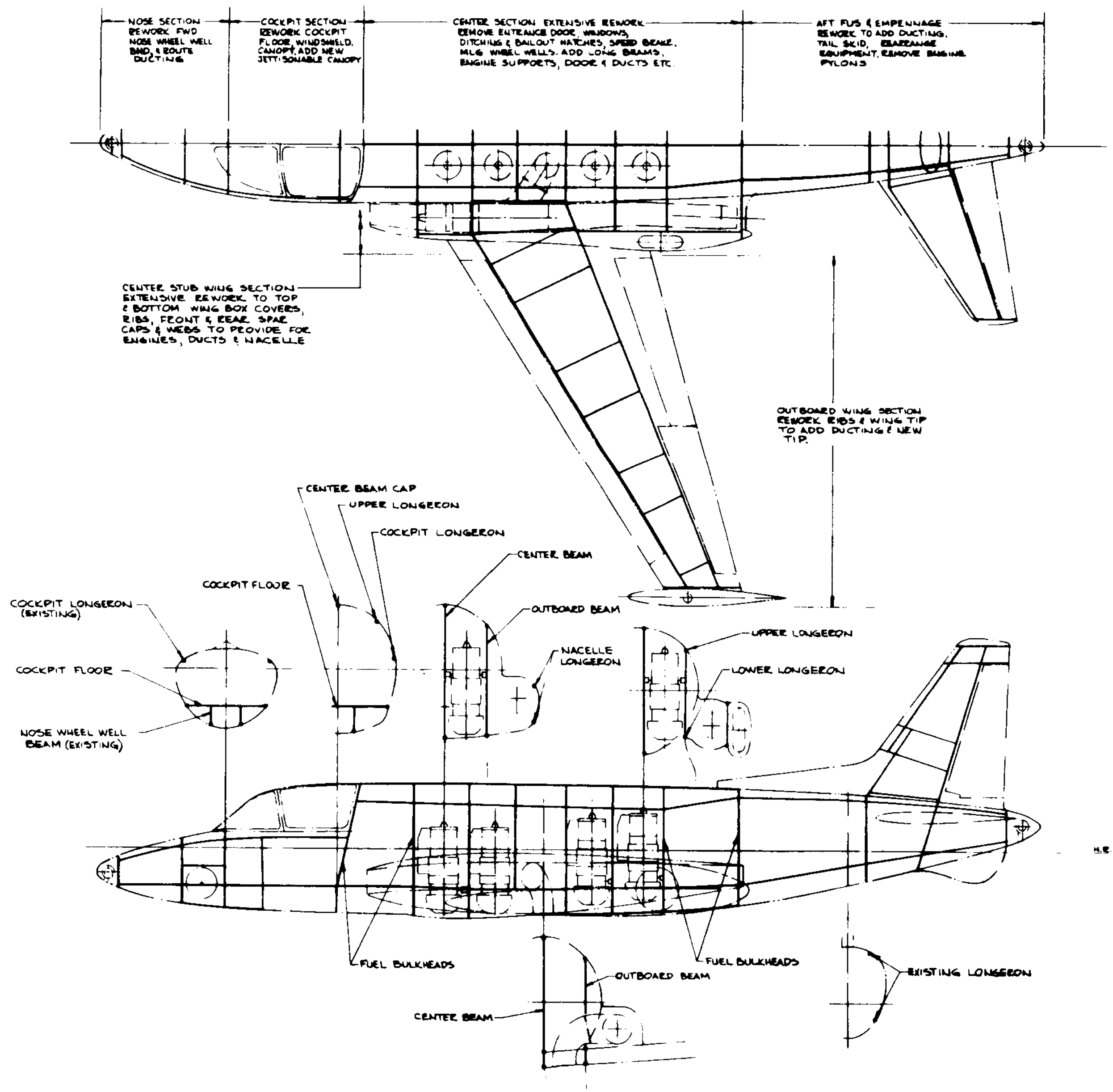


Figure 20. Structural Diagram - Concept J

Weight and Balance Considerations

Group Weights. - The summary of group weights for Concepts C and J is presented in Table 10.

TABLE 10. SUMMARY OF GROUP WEIGHTS

Item	Concept C 8 J85 14 Min.	Concept J 10 J85 12 Min
Structure	(3,691)	(5,907)
Wing	724	1,978
Tail	364	297
Body	1,980	2,740
Landing Gear	623	892
Propulsion and Nacelle	(4,666)	(5,887)
Engines	3,296	4,090
Air Induction	118	170
Exhaust	584	695
Fuel System	272	308
Engine Controls	64	80
Starting	56	70
Nacelle/Engine Section	276	474
Power System	(1,235)	(1,573)
Surface Controls	436	582
VTO Controls	240	420
Hydraulic and Pneumatic	153	157
Electrical	406	414
Equipment Groups	(830)	(827)
Instruments and Navigation	150	150
Electronics	185	185
Furnishings	352	348
Air Conditioning	143	144
Contingency	(106)	(297)
Weight Empty	10,528	14,491
Crew	400	400
Oil, Oxygen and Trapped Fuel	132	180
Payload	800	800
Hover Fuel	3,440	3,886
VTO Gross Weight	15,300	19,757
Ramp Fuel	270	324
Ramp Gross Weight	15,570	20,081

Center of Gravity Envelopes. - In Figures 21 and 22 are presented the center-of-gravity envelopes for the Concept C design with eight YJ85-GE-19 engines, and the Concept J design configuration with ten YJ85-GE-19 engines, respectively. In each instance, the envelope is for a weight range from full fuel (at VTO weight) to zero fuel under the following loading conditions: a) flight with either or both pilots, and b) flight with full research payload of 800 pounds down to 500 pounds of payload (variable stability equipment alone).

It is worth noting that the envelopes maintain reasonable symmetry with reference to the combined engine centers of thrust, thus indicating the feasibility of normal fuel sequencing for either design. Ballast was not considered in calculating these envelopes.

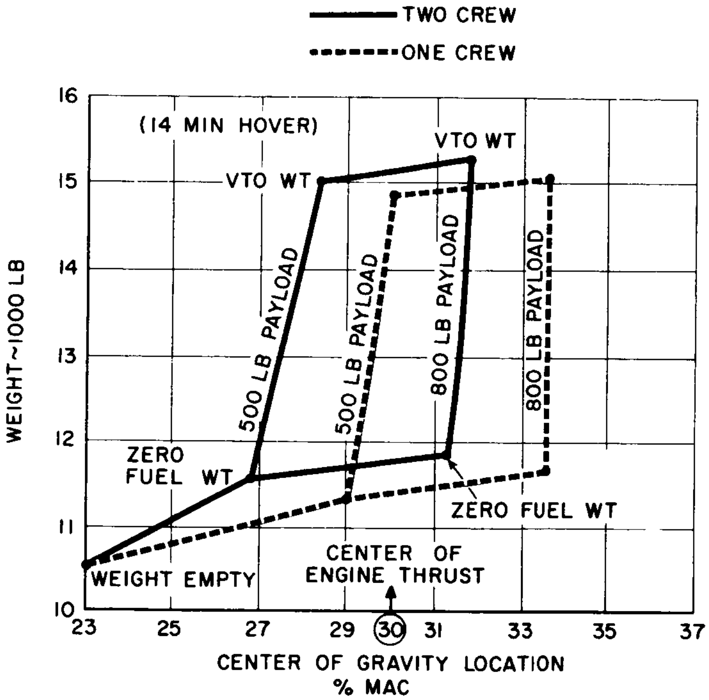


Figure 21. Center of Gravity Envelope - Concept C

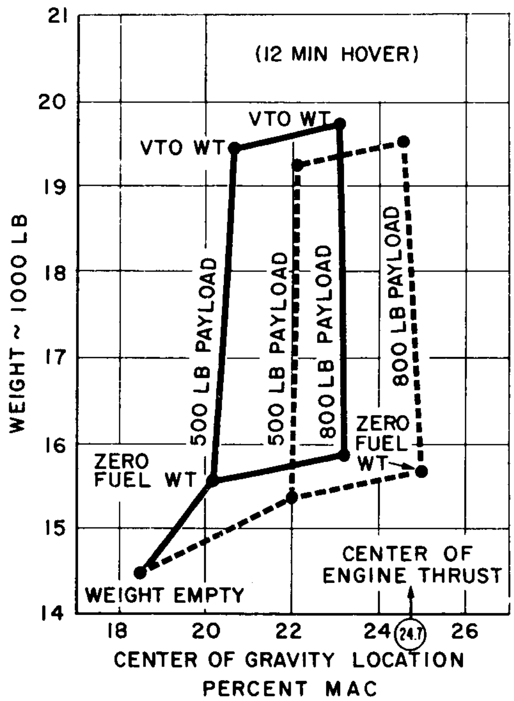


Figure 22. Center of Gravity Envelope - Concept J

Effect of Weight Growth on Hover Endurance. - Figure 23A shows the effect of operating weight empty growth on hover time for a "frozen" Concept C configuration with a VTO weight held constant at 15,300 pounds, and then held constant again at 16,000 pounds. For the first case, the solid line indicates the reduction in hover time as the weight empty increases, and the increase in hover time as the weight empty decreases for instances where more fuel can be added. For the second case, the broken lines indicate the effect of permitting a gradual change in VTO weight (holding the fuel quantity constant) up to a maximum of 16,000 pounds and then offloading fuel for further increases in weight empty. The latter case corresponds to a reduction of 3% in the required thrust-to-weight ratio for the maximum hover time design point.

Figure 23B shows the similar effects for the Concept J design for VTO weights held constant at 19,760 and 20,000 pounds, respectively.

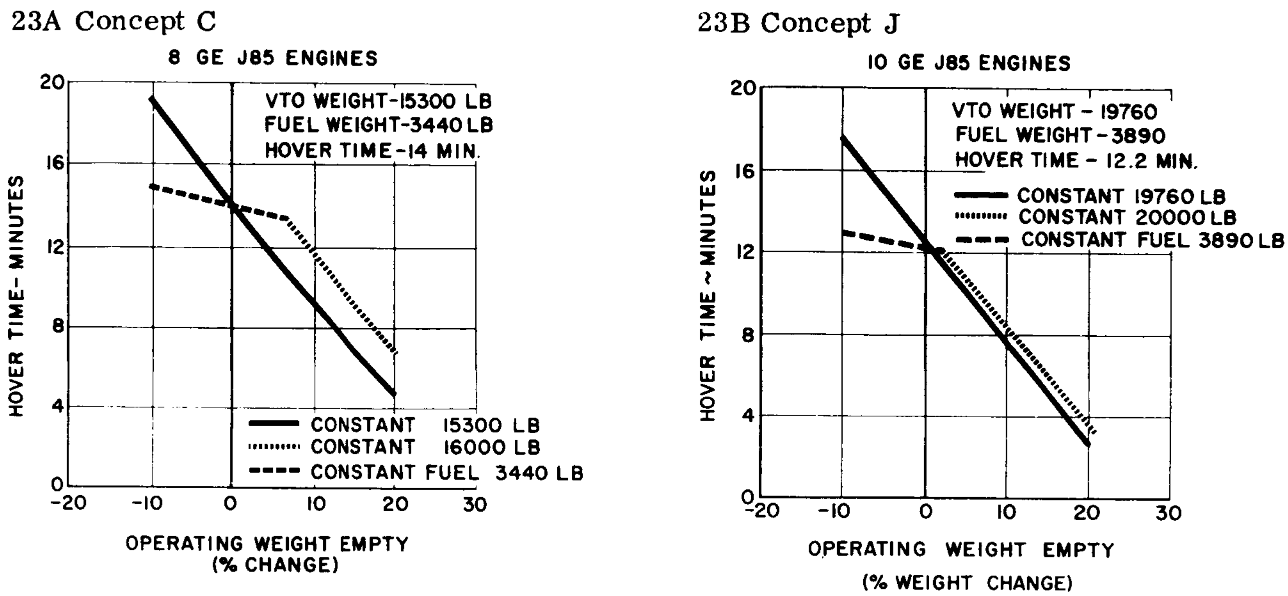


Figure 23. The Effect of Weight Growth of Hover Time

<u>Effect of Weight Growth at Constant Hover Endurance - Concept C</u>. - In Figure 24 is shown how the Concept C VTO gross weight (for constant hover time) is affected when changes in operating weight empty occur. For example, if this weight empty were to increase by 10% (1100 pounds) the take-off gross weight would increase approximately 2200 pounds. The operating weight empty is defined as the VTO gross weight less fuel and 800 pounds of payload.

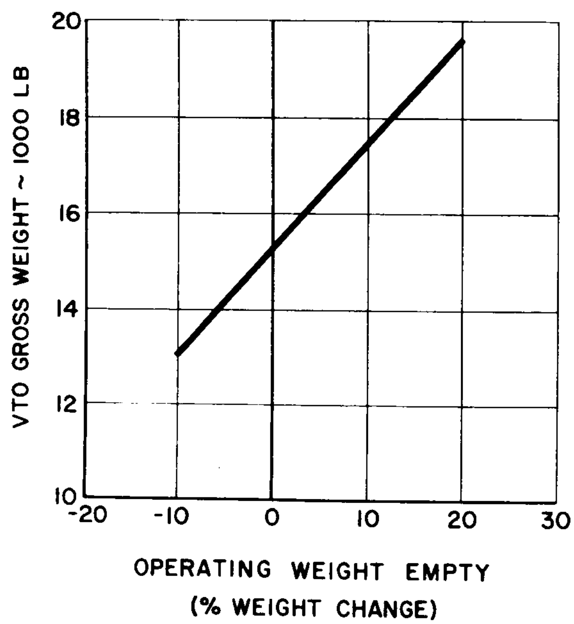


Figure 24. Constant Hover Endurance Weight Growth - Concept C

Weight Correlation. - The basic weight trends for several contemporary V/STOL aircraft and the selected Concepts C and J configurations are given in Table 11. A group gross weight breakdown of well defined groups is presented permitting a quick check of the new aircraft weight estimates. Correlation is excellent with values for actual hardware V/STOL aircraft (XV-4A, XV-5A, and P 1127) but differs substantially in the structures and propulsion groups from the XV-4B.

The aircraft gross weights are with maximum internal fuel (full ramp fuel for most weights). For Concepts C and J, the corresponding VTO weights are 15,300 and 19,760 pounds, respectively.

TABLE 11. WEIGHT CORRELATIONS - CONCEPTS C & J vs OTHER V/STOL AIRCRAFT

Aircraft / Item	XV4A		XV4B		XV5A		P1127		Concept C 8 Engines		Concept J 10 Engines	
	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%
Structure	2018	28.0	2225	16.8	3149	26.0	3804	24.6	3691	23.7	5907	29.4
Propulsion and Nacelle	1893	26.3	3279	24.8	3664	30.3	4199	27.2	4666	30.0	5887	29.3
Power Systems	924	12.8	1140	8.6	751	6.2	1318	8.5	1235	7.9	1573	7.8
Equipment Groups	343	4.8	614	4.7	408	3.4	956	6.2	830	5.3	827	4.1
Contingency/Misc.	-	-	-	-	109	0.9	55	0.4	106	0.7	297	1.5
Useful Load	2022	28.1	5962	45.1	4012	33.2	5108	33.1	5042	32.4	5590	27.9
Gross Weight	7200	100.0	13220	100.0	12093	100.0	15440	100.0	15570	100.0	20081	100.0

Structural Design Criteria Comparison

Landing Gear Capability. - The landing gear of Concept C fully meets the NASA ground loads and sink speed requirements. A modified existing main gear strut is available for Concept C. A new landing gear is required for the Concept J (modified Sabreliner). The higher design landing weight, airframe structural limitation, and geometry of the Concept J aircraft limits the sink speed in the VTOL mode to 11.3 ft/sec; the NASA requires 15 ft/sec. Table 12 presents a summary of the landing gear capability of both aircraft.

TABLE 12. LANDING GEAR CAPABILITY OF CONCEPTS C AND J

Concept	Design Landing Weight (lb)	Landing Mode	Ground Reaction Load Factor	Airplane Load Factor	Stroke (inches)	Sink Speed (ft/sec)
C	15300	VTOL	2.62	3.29	20	15
		CTOL	1.52	2.52	20	12
J	19760	VTOL	1.76	2.43	18	11.3
		CTOL	1.60	2.60	18	12

V-n Diagrams. - The flight envelopes at sea level for Concepts C and J are shown in Figures 25 and 26, respectively. Concept C fully meets the NASA load factor requirements of 3.75 positive and 1.5 negative. Concept J is shown for maneuver limit load factor of 3.0 positive and 1.0 negative. This assumes that Concept J will be reinforced and structurally tested to the same strength level as the stretched series -60 Sabreliner.

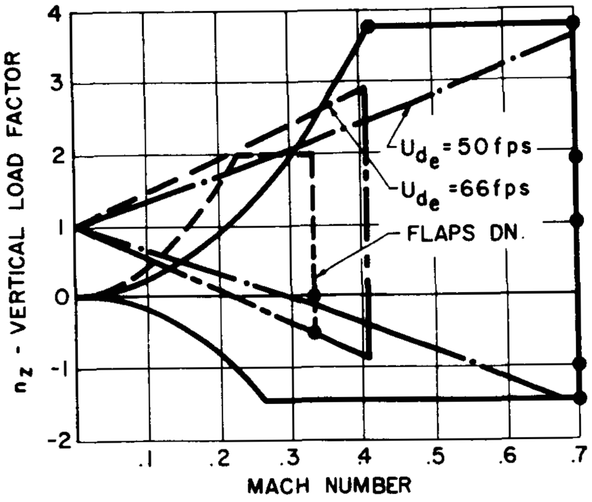


Figure 25. V-n Diagram - Concept C

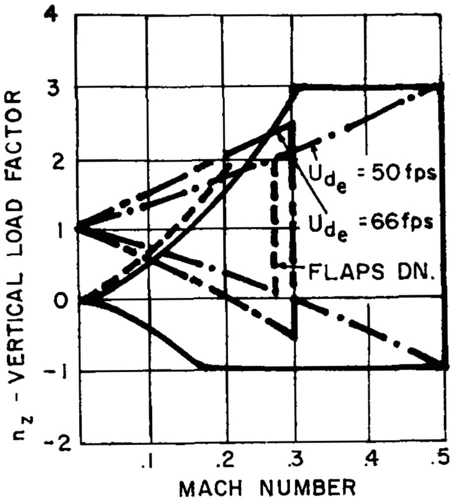


Figure 26. V-n Diagram - Concept J

Performance Comparison

Rate of Climb - One Engine Out. - In the Statement of Work the specified climb requirement is that the aircraft shall be able to continue conventional flight with the failure of a single cruise engine down to 1.2 times the power off stall speed, approach flap setting, lift engine doors open, lift engines windmilling and the landing gear extended. Under these conditions, Concept C, with approach flaps at 20 degrees, has a rate-of-climb better than 100 ft/min at sea level, 80°F, and design VTO weight. It will maintain a positive rate-of-climb at altitudes up to 2300 feet, 100°F, for weights below 13,650 pounds (Figure 27a). Similarily, Concept J with flaps deflected 25 degrees, has a rate-of-climb of almost 100 ft/min at sea level, 80°F, and VTO weight. At 2300 feet, 100°F, it will maintain altitude at a weight of 17,200 pounds (Figure 27b). Adequate rate of climb margin is therefore available for both aircraft in the emergency condition.

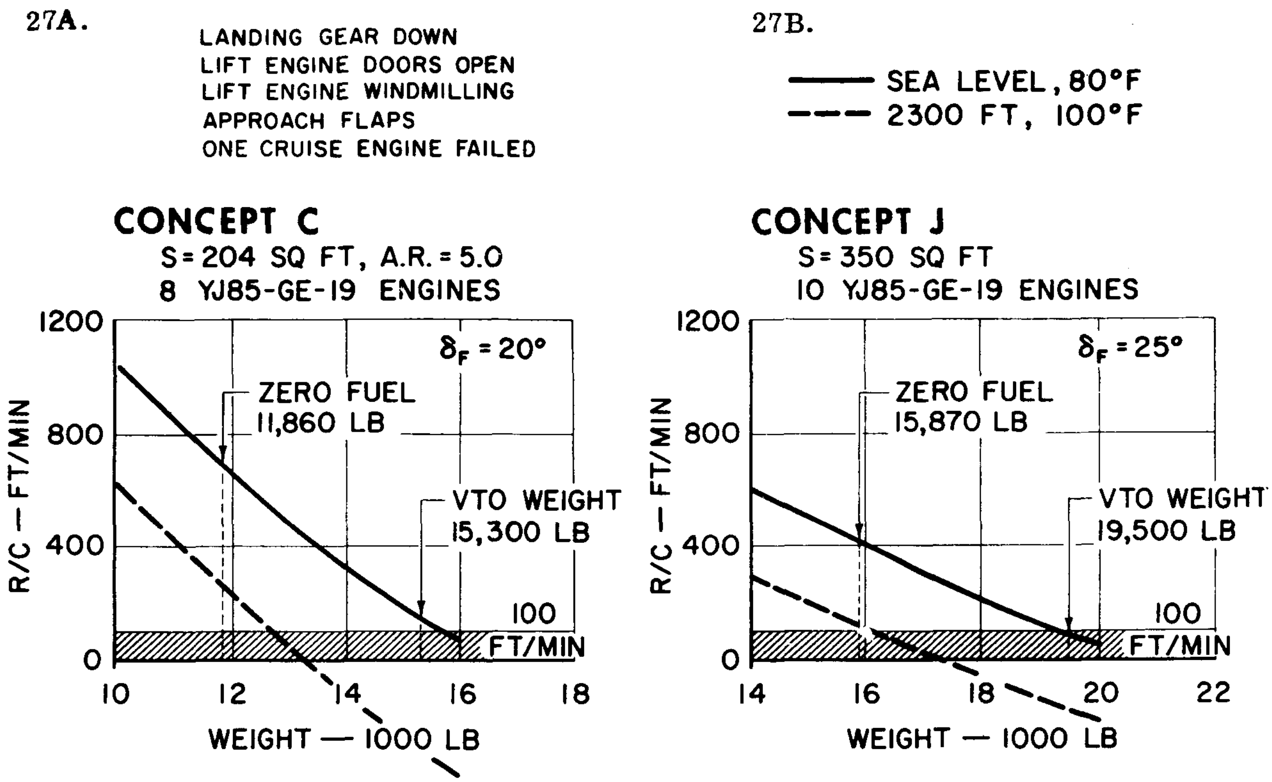


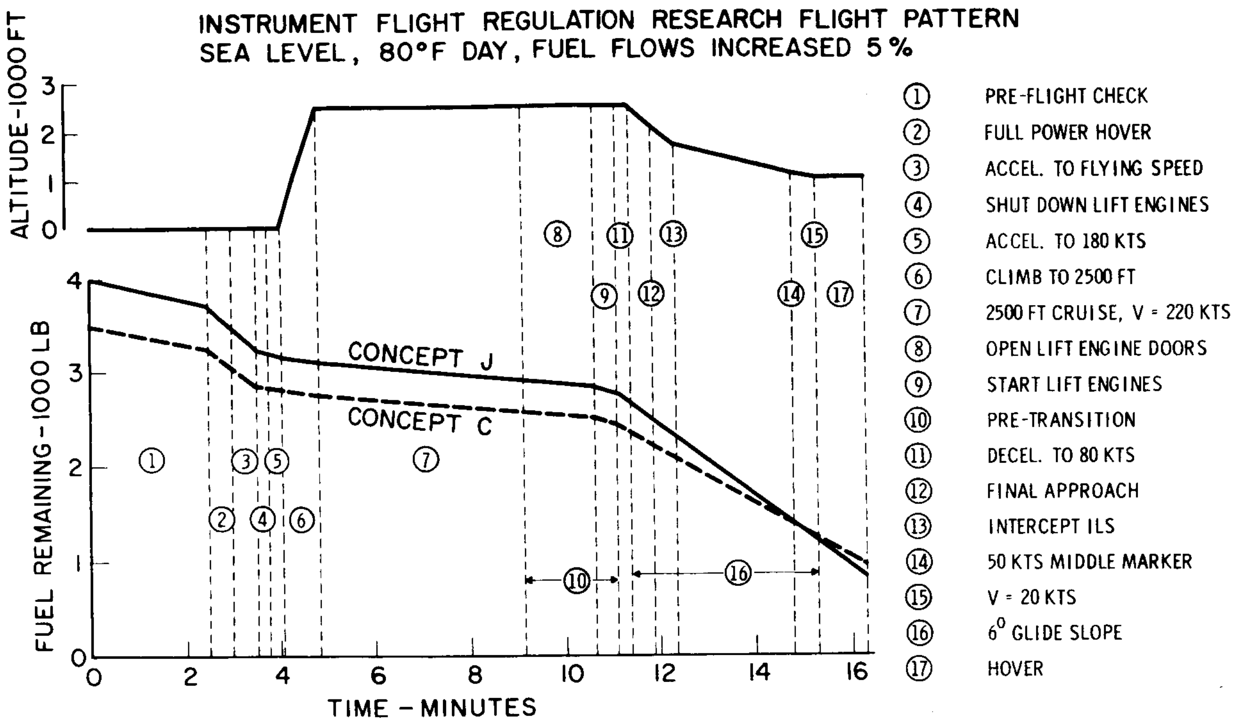
Figure 27. Rate of Climb with One Engine Out at 1.2 Stall Speed

Circuit Performance. -The Instrument Flight Regulation research flight pattern fuel and altitude-time history are presented in Figure 28. A 2.5 minute checkout including engine warmup precedes the flight. The aircraft then does a vertical lift-off at full power to hover out of ground effects. A 30-second acceleration to transition and lift engine shutdown is followed by an acceleration and climb to 2500 feet. The vehicle cruises at 2500 feet to prepare for a vertical landing. This covers approximately 16 nautical miles.

For the landing, the vehicle decelerates to open the lift-engine doors and start the lift engines. After starting the lift engines, it decelerates to 80 knots for a glide approach and vertical landing.

The rates of descent on a 6-degree glide slope started with an average of 800 feet/minute and was reduced to an average of 200 feet/minute prior to hover and vertical descent.

Both aircraft designs have adequate fuel to fulfill the required research flight pattern as indicated below.



	Concept C	Concept J
Engines	2 L/C + 6 Lift	2 L/C + 8 Lift
Initial Weight (pounds)	15300	19500
Initial Fuel (pounds)	3440	3970
Final Weight (pounds)	12789	16384
Final Fuel (pounds)	929	854

Figure 28. Circuit Performance - Concepts C and J

Standard Aircraft Characteristics. - Performance charts are presented in Figures 29 and 30 for concepts C and J, respectively.

Take-Off. - Take-off distances are presented as a function of gross weight on a calm day at sea level, 80°F and 100°F. The take-off ground run distance and the total distance to clear 50 feet are presented.

Climb. - Rate-of-climb is presented as a function of altitude at basic mission weights with military and normal power. The Concept C basic mission weights shown are take-off at 15,570 pounds including full internal fuel and 12,420 pounds during a ferry mission with remaining reserve fuel of 5 percent initial fuel plus fuel for 20 minutes at speed for maximum endurance at sea level. The corresponding Concept J weight values are 19,830 lbs and 16,497 lbs, respectively. Rates of climb shown were corrected for changes in kinetic energy due to forward acceleration. A time-to-climb curve conforming to this performance data is included.

Speed. - Speed is presented as a function of altitude at the basic mission take-off weight with maximum internal fuel capacity at military and normal power.

Range. - The ferry range is presented vs average cruise airspeed from minimum acceptable flight speed to maximum speed with normal power at representative high cruising altitude.

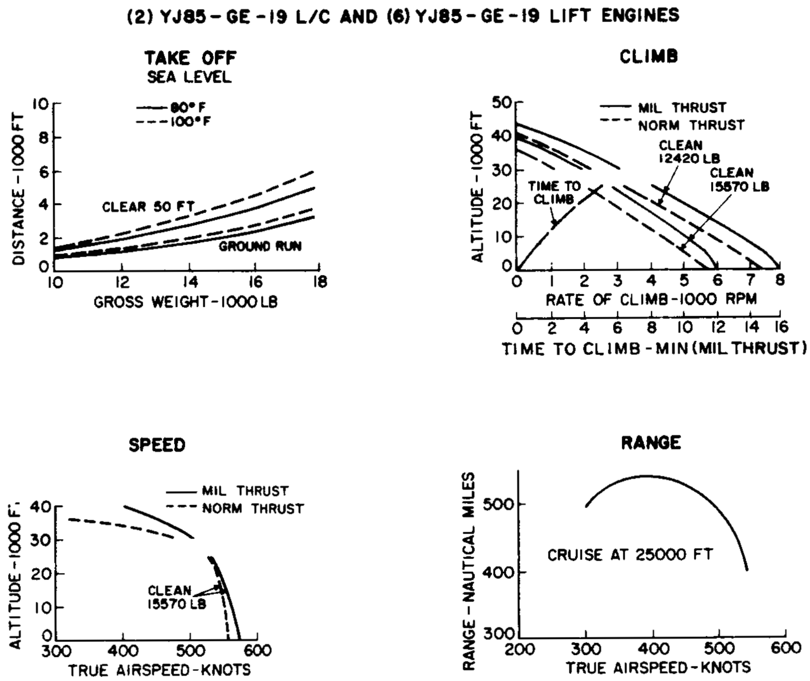


Figure 29. Aerodynamic Performance SAC Chart - Concept C

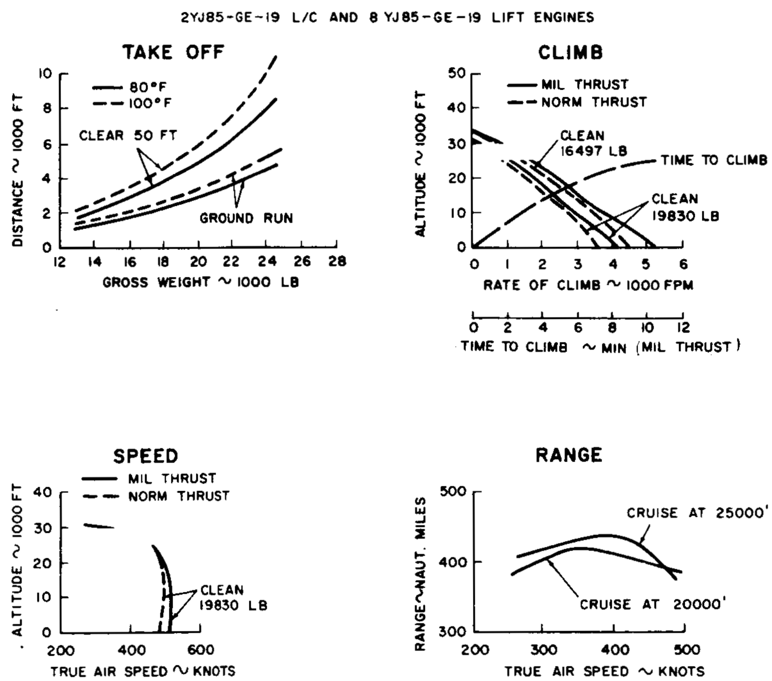


Figure 30. Aerodynamic Performance SAC Chart - Concept J

Stall Speeds. - The stall speed variation with weight is presented in Figure 31 for flaps up and flaps down for Concepts C and J.

For Concept C, in the left hand plot, the upper and lower limit power-off stall speeds are 145 and 105 knots, at the design VTO gross weight of 15,300 pounds. The stall speed spread is achieved by use of a retractable leading edge slat or, alternatively, a fixed leading edge droop in conjunction with a lift spoiling device.

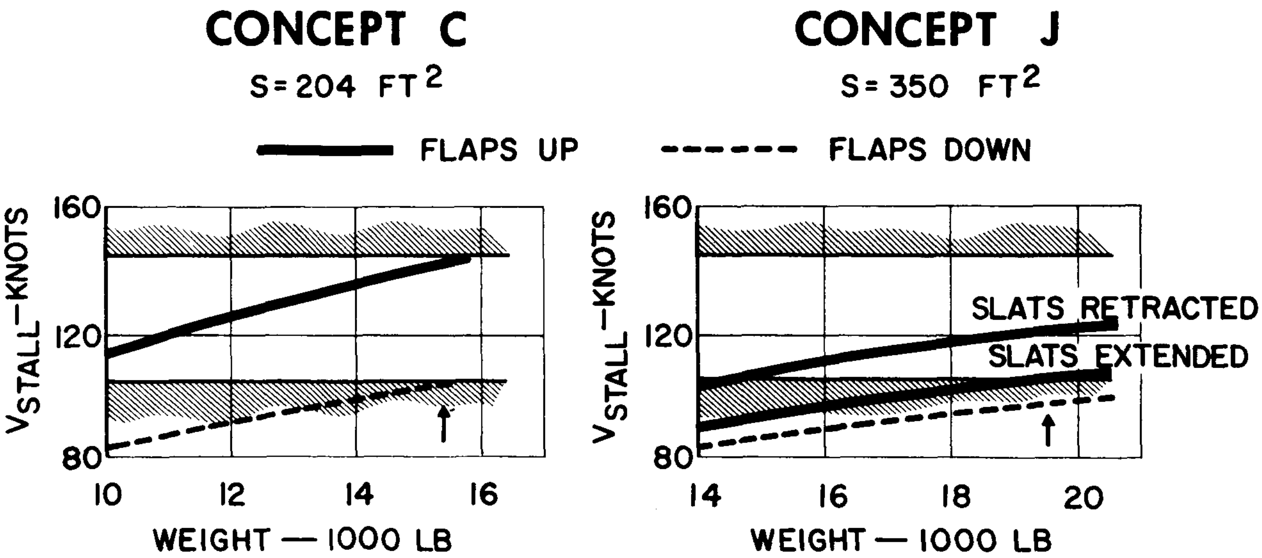


Figure 31. Stall Speeds - Concepts C and J

For Concept J the NASA specified power-off stall speeds and stall speed spread cannot be achieved. The incremental change in stall speed for the design configuration with leading edge slats automatically extended is approximately 8 knots, which is considerably below the specified stall speed spread of 40 knots. Modification to a manually controllable leading edge flap or slat system will increase the stall speed spread to 23 knots. However, the stall characteristics are indicated to be unsatisfactory with the leading edge slat retracted.

Flying Qualities Comparison

Concept C. - In Figure 32 is presented the trim angle-of-attack and stabilator deflection for level flight. The rudder deflection to maintain sideslip, and the short period oscillatory flight mode (Dutch Roll) dynamic longitudinal stability and roll characteristics are also included.

Trim Angle of Attack. - Trim angle-of-attack variation (at a cg position of 30 percent $\bar{c}$) with Mach number and altitude shows angles less than 12 degrees above Mach 0.4. The stall angle-of-attack is also shown. (Figure 32A)

Trim Stabilator Deflection. - Trim stabilator deflection angles are presented as a function of Mach number and altitude. These deflection angles and the corresponding trim drag can be reduced by a reduction in the static margin. (Figure 32B)

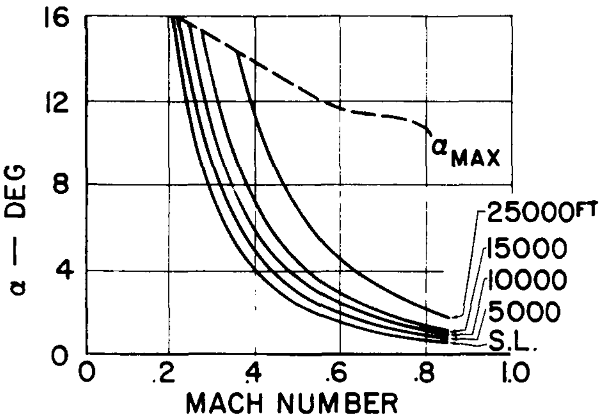


Figure 32A. Trim Angle of Attack

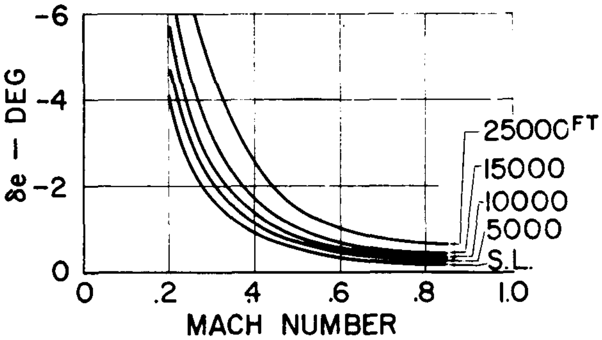


Figure 32B. Trim Stabilator Deflection

Rudder Deflection. - Rudder deflection per sideslip angle is positive over the Mach number range. (Figure 32C)

Dynamic Lateral Stability. - The short-period lateral oscillations are presented in terms of the reciprocal of the cycles to damp to one-half amplitude and the bank angle relation to side velocity. The Air Force criterion of the minimum damping requirement with stability augmentation, USAF MIL-F-8785 (ASG), is also shown. This shows that the airframe without stability augmentation will meet this requirement for all flight conditions investigated. (Figure 32D)

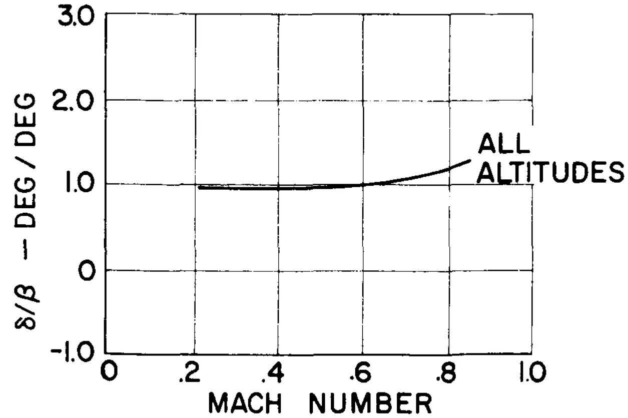


Figure 32C. Rudder Deflection per Unit Sideslip

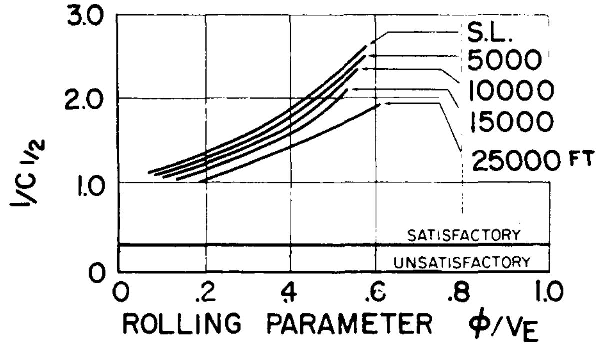


Figure 32D. Dynamic Lateral Stability

Dynamic Longitudinal Stability. - The dynamic longitudinal stability is presented in terms of the natural frequency, ω_n (cycles per second), and damping ratio, ζ, of the airframe alone as a function of altitude and Mach number. Boundaries are shown of the desirable and satisfactory piloted airframe regions. The basic airframe characteristics vary considerably over the flight range from low speed to Mach 0.8. For most flight conditions, the characteristics appear satisfactory or desirable. (Figure 32E)

Roll Characteristics. - The roll characteristics are presented on the basis of the steady-state roll rate and roll time constant. The roll characteristics are good at high subsonic speeds (M = 0.8) and are acceptable at the high angles of attack of the low speed range. The pilot opinion boundaries shown are the flying quality requirements based on NATO AGARD R-336. (Figure 32F)

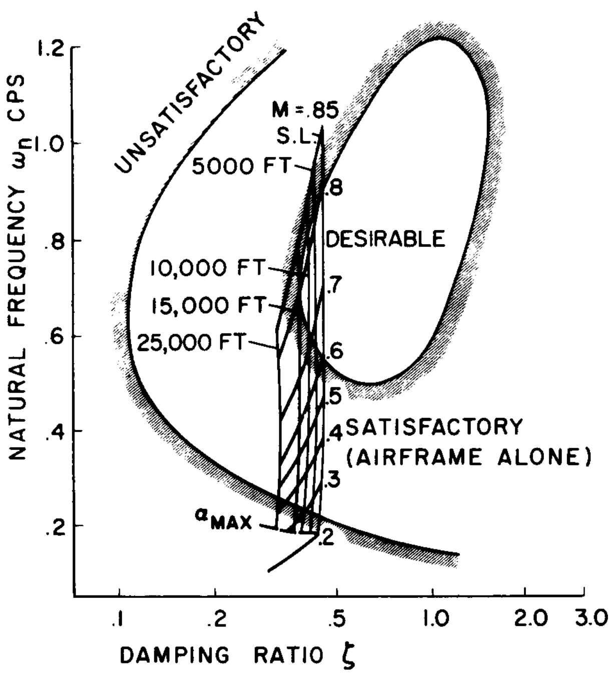


Figure 32E. Dynamic Longitudinal Stability

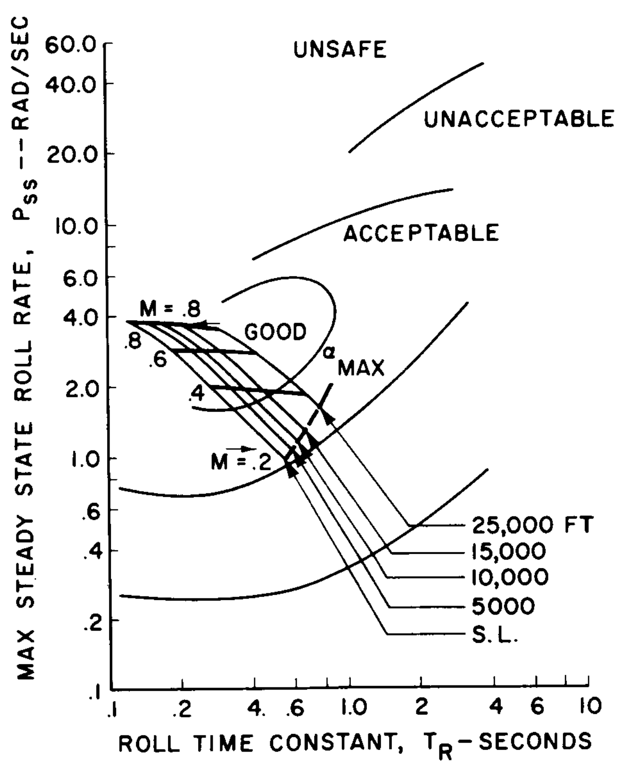


Figure 32F. Roll Characteristics

Concept J. - The trim angle-of-attack and elevator deflection for level flight are presented in Figure 33. Also included are rudder deflection to maintain sideslip, short period oscillatory flight mode (Dutch Roll) characteristics, dynamic longitudinal stability, and roll characteristics.

Trim Angle of Attack. - Trim angle-of-attack variation (at a 30 percent cg position) with Mach number and altitude shows angles less than 8 degrees above Mach 0.4. The stall angle-of-attack of 18° is not exceeded in level flight. Lower trim angles-of-attack can be achieved by increased stabilizer area. (Figure 33A)

Trim Elevator Deflection Angles. - Trim elevator deflection angles are presented as a function of Mach number and altitude. These deflection angles and the trim drag corresponding to them can be reduced by a reduction in the static margin. (Figure 33B)

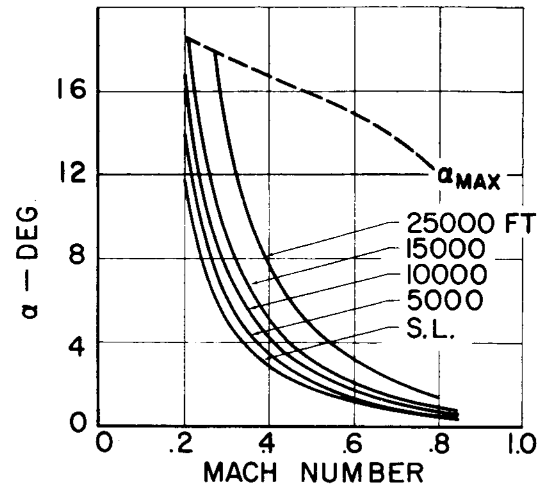


Figure 33A. Trim Angle of Attack

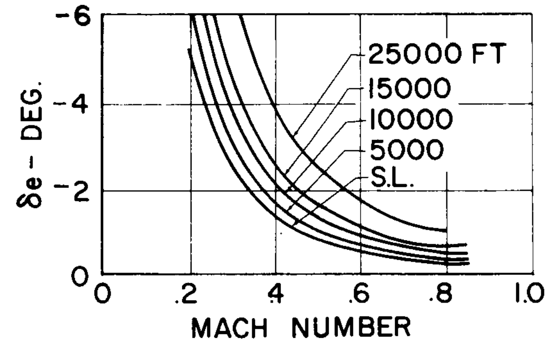


Figure 33B. Trim Elevator Deflection

Dynamic Lateral Stability. - The short-period oscillations are presented in terms of the reciprocal of the cycles to damp to one-half amplitude and the bank angle relation to side velocity. This is also the Dutch Roll damping parameter and the rolling parameter. The minimum damping requirement with stability augmentation, USAF MIL-F-8785 (ASG), is also shown. This shows that the airframe without stability augmentation will meet this requirement for all flight conditions investigated. (Figure 33D)

Rudder Per Unit Sideslip. - Rudder deflection per unit sideslip angle varies from negative to positive. The negative values in the low-speed range are due to the high dihedral effect, $C_{\ell\beta}$, at high angles-of-attack. USAF MIL-F-8785 (ASG) specifies positive δ_r/β. Reducing the dihedral angle would constitute a major modification. (Figure 33C)

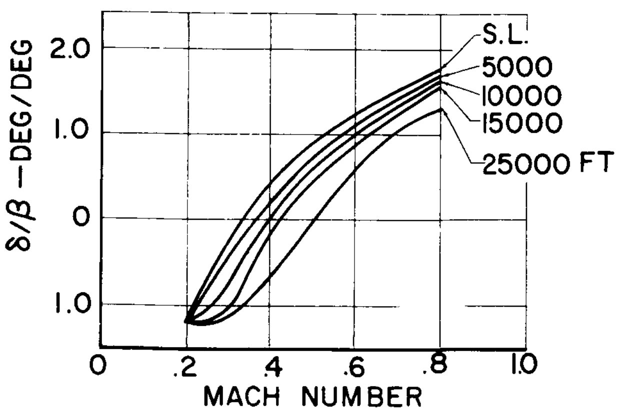


Figure 33C. Rudder Deflection

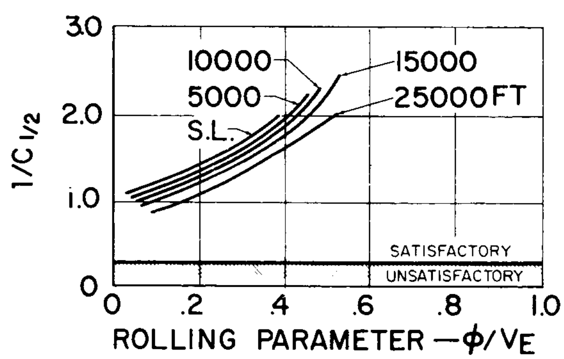


Figure 33D. Dynamic Lateral Stability

Dynamic Longitudinal Stability. - The dynamic longitudinal stability is presented in terms of the natural frequency, ω_n (cycles per second), and damping ratio, ζ, of the airframe alone as a function of altitude and Mach number. Boundaries are shown of the desirable and satisfactory piloted airframe regions. The basic airframe characteristics vary considerably over the flight range from low speed to Mach 0.8. For most flight conditions, the characteristics are either satisfactory or desirable. (Figure 33E)

Roll Characteristics. - The roll characteristics are presented in terms of the steady state roll rate and roll time constant. The roll characteristics are unacceptable in the low-speed range (M = 0.2) but become acceptable in the high-speed range. Most of these roll characteristics can be brought into the good or acceptable characteristics area with the automatic flight control system. (Figure 33F)

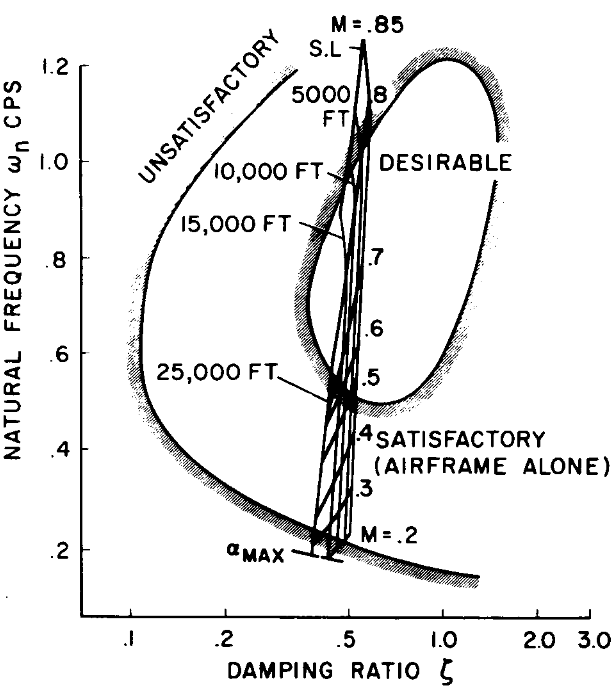


Figure 33E. Dynamic Longitudinal Stability

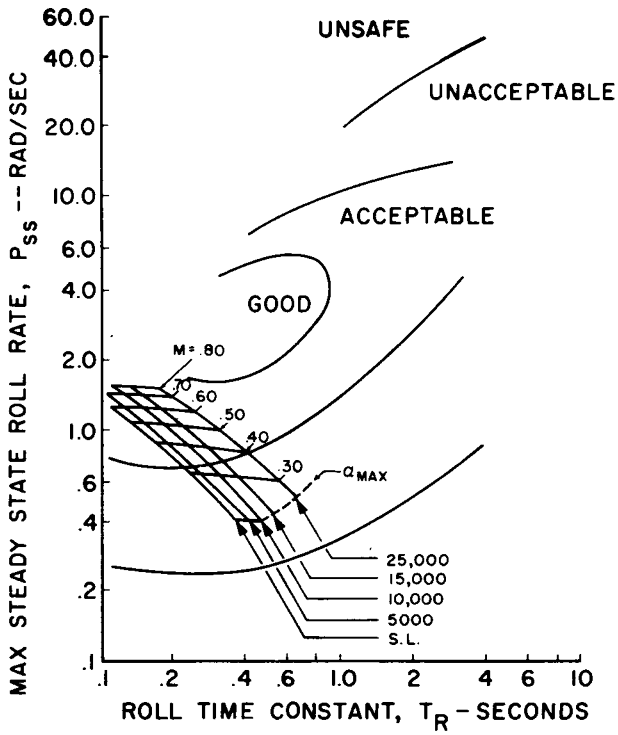


Figure 33F. Roll Characteristics

Transition Flight Mode. - The effects of jet exhausts on static lateral stability have been predicted through the transition flight speed range by comparison and correlation of Concepts C and J with unpublished NASA test data.

A review of the lateral control margin in transition, at a specified maximum sideslip angle of 15 degrees, or a sideslip angle equivalent to a 35-knot sidewind above 135 knots, shows the need for both high angles of attack and appreciable flap deflections in the speed range from 60 to 135 knots. The alternative solution is to restrict design flight criteria to more moderate sideslip angles at speeds above 60 knots.

For Concept J, in the speed range between 50 and 140 knots, the lateral trim requirements exceed the trim available at a 15 degree sideslip even with a 10 degree angle of attack with approach flaps (25 degrees). Concept C requirements, however, are well within the lateral trim available under the same conditions.

Propulsion and Thermodynamic Comparison

Ground Temperature and Velocity Environment. - The temperature and velocity ground flow fields for the C and J concepts incorporating YJ85-GE-19 and RB162-81 engines are shown. Of these arrangements, Concept C, with YJ85 engines, presents the least problem with regard to tire heating (350°F gas at 300 fps), while Concept J with RB162 engines, is the most severe (1050°F gas at 913 fps). The tire heating rates are high due to the high gas velocities (32 and 63 BTU/hr/ft/°F, respectively, for the above cases), with tire carcass surface temperatures approaching local gas temperature very rapidly (Figure 34).

Lift engine air inlets should be free of hot gas ingestion with the lift-cruise engine side inlet air temperatures rising from 5° to 12° during ground run-up. This is predicated on the assumption that the engines are arrayed to successfully avoid the formation of forward flowing fountains.

Means to cope with hot gas heating of wing root, fuselage, and nacelle under surfaces must be provided (e.g., thin insulated steel overskins which can be attached locally as needed). Definition of design criteria for engine throttle setting, nozzle position, and aircraft altitude-time histories during take-off and landing must be as realistic as possible, since conservatism can impose high penalties in the form of thermal protection devices.

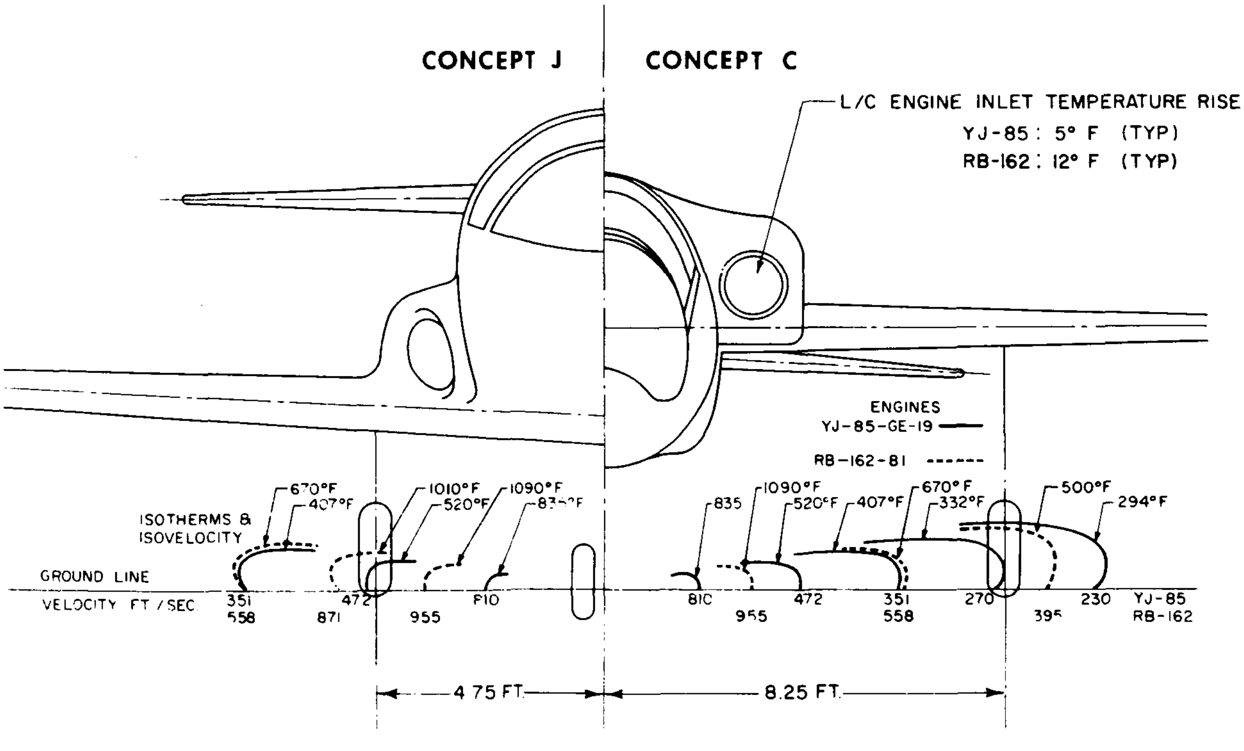


Figure 34. Ground Temperature and Velocity Environment

Lift Engine Air Start. -Simultaneous air start of lift engines is a problem at the airspeeds specified by the NASA. A minimum equivalent airspeed of 225 knots is required in order to achieve a ram air start of the YJ85-GE-19 engine. NASA requirements specify simultaneous air starts at airspeeds between approximately 150 percent of power-off stall speed, flaps-up, and 120 percent of power-off stall speed with approach flaps. It appears feasible to achieve a simultaneous air start of the six (6) YJ85-GE-19 lift engines in the Concept C aircraft; however, the eight (8) YJ85-GE-19 lift engines in Concept J would entail starting in two (2) banks of four (4) each (Figure 35).

A simultaneous air start of the six (6) YJ85-GE-19 can be achieved by utilizing 10% bleed air from the two (2) lift-cruise engines for lift engine turbine impingement as an assist to ram air. At low cruise thrust requirement levels, bleed air horsepower can be maximized by presetting the lift-cruise engine diverter valve in an intermediate position rather than vertical or horizontal, and advancing the throttle.

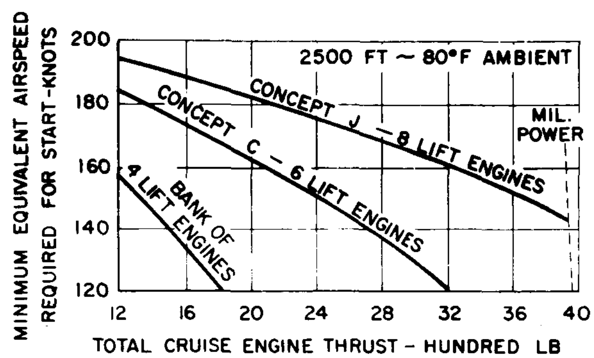


Figure 35. Lift Engine Air Start - Concepts C and J

The values of airspeed corresponding to the NASA requirement above are approximately 150 and 115 knots for Concept J and about 200 and 120 knots for Concept C, for approach flaps up and down, respectively.

Vectoring System. -A pivoting sphere lift thrust vectoring nozzle having ±30 degrees deflection capability was assumed for both new and modified aircraft concepts. Figure 36 presents a comparison of the General Electric/Air Force pivoting sphere nozzle with the General Electric improved pivoting sphere nozzle when installed on either the lift engine or the lift-cruise engine. A pivoting sphere nozzle installation on the lift-cruise engine includes a diverter valve installation with its inherent leakage and pressure drop. The vectoring nozzle area must therefore be greater in this case, otherwise an engine overtemperature condition will exist. Pivoting sphere nozzles on the diverted lift-cruise engine tailpipe are not shown in Figures 16 and 19, but such nozzles were incorporated later in order to improve transition times for acceleration and deceleration.

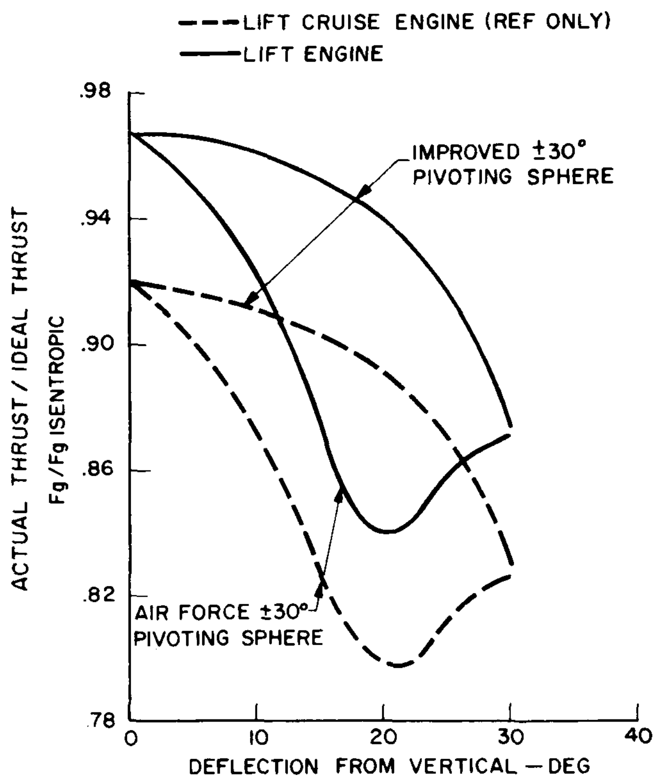


Figure 36. Vector System Performance

Subsystem Comparison

Crew Stations. - Concept C has tandem cockpits. The forward cockpit is the evaluation pilot's crew station (Figure 37a) and the aft cockpit is the safety pilot's crew station (Figure 37b). Both crew stations have the required NASA visibility. The evaluation pilot's displays are representative of future high performance V/STOL aircraft. The Concept C crew stations meet the specifications issued by the NASA to the fullest extent feasible.

Figure 38 shows the proposed arrangement for controls and displays for the side-by-side seating of Concept J. In this concept, the entire crew compartment must be redesigned for escape capability, which required 1) a new windshield and canopy 2) new aft bulkhead 3) ejection seats 4) control sticks instead of control wheels 5) revision of structural members, panels, consoles and pedestals for escape envelope clearances.

In addition to these, three basic problems exist with respect to crew station requirements: 1) required external vision cannot be met with the modified vehicle, although visual capability is slightly improved with a new windshield/canopy configuration, 2) anticipating the structural design requirements to incorporate the new windshield/ canopy, it is difficult to assure adequate hand clearance for the evaluation pilot's operation of engine power controls, and 3) an effective location for the evaluation pilot's side-stick (provisions requirement) does not exist. Its optimum position, based on human factors considerations, is occupied by the safety pilot's engine power controls. While it may be possible to incorporate provisions for such control as an integral part of the seat arm rest or as detachable unit, safe escape may be compromised. No other location can be considered suitable.

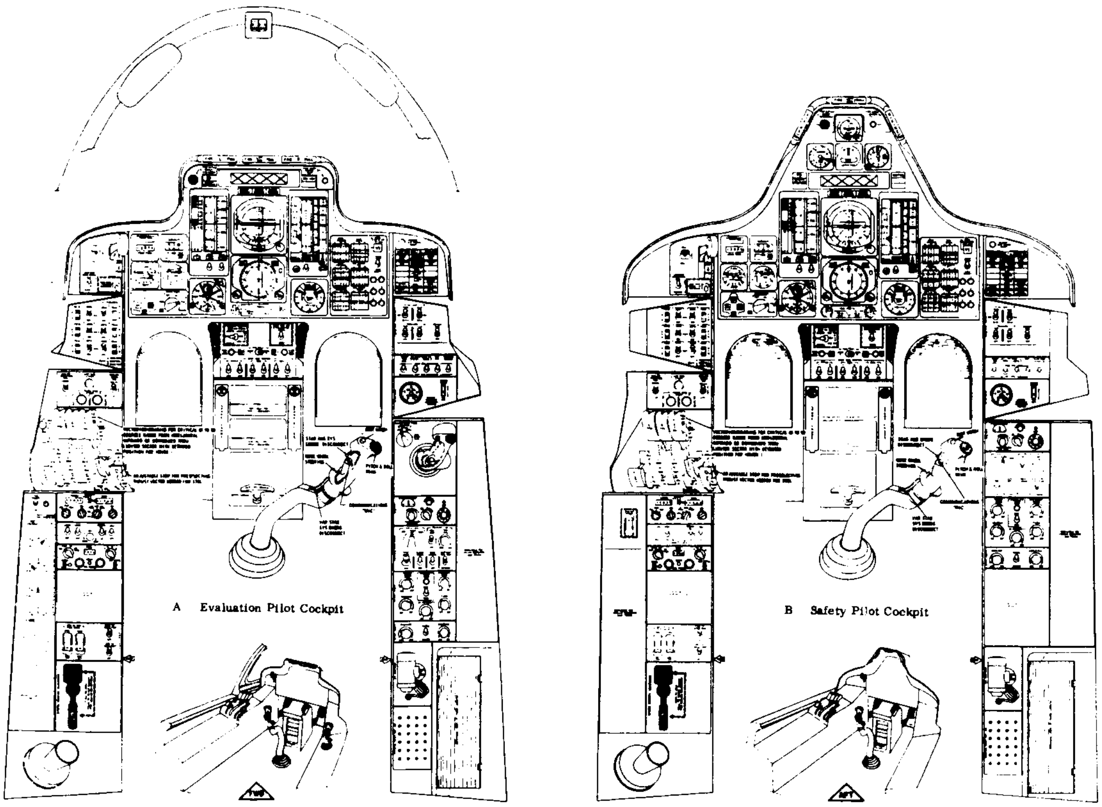


Figure 37. Crew Station Layout-Concept C

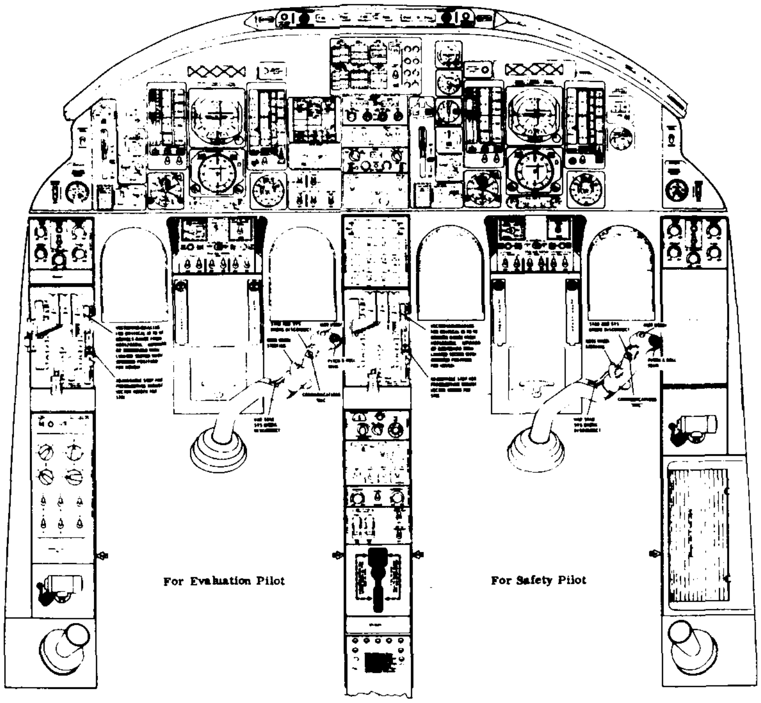


Figure 38. Crew Stations Layout-Concept J

Escape Systems. - The escape system under consideration for both concepts, has the basic capability of zero altitude-zero velocity performance, high-impulse rocket performance, forced personal parachute deployment, positive and sustained seat and man clearance subsequent to seat/man separation, and automatic deployment of survival kit during the ejection cycle. A significant factor in the selection of this escape system is that a considerable part of the configuration is scheduled for testing in July 1967 at Holloman AFB. This testing can also serve to confirm the design for the NASA V/STOL program.

The safe decision time lag from the time of occurrence of the emergency in hover to separation from the seat catapult rails is assumed to be a maximum of three seconds. This decision time lag is sufficient for a single pilot but insufficient for two pilots. In such a hover flight emergency condition, where the second pilot is not in a position to receive the emergency cue, the first pilot will initiate both escape systems.

In Concept C, the evaluation (front) pilot may not sense the emergency cue; therefore, the safety (aft) pilot will eject the evaluation pilot then himself in an automatic sequence. In Concept J, either pilot can eject both pilots automatically at the same time. The evaluation pilot in the front cockpit of Concept C can only eject himself in a hover flight emergency because the safety pilot in the aft seat can positively sense the departure of the front canopy and seat/man assembly and therefore can command his own ejection.

The crew escape sequence in both concepts features automatic canopy jettison followed by catapult seat ejection. A safe sustained rocket motor thrust brings the man to a safe altitude for parachute descent and recovery. The seat separates from the aircraft in 0.50 seconds and the parachute is fully blossomed in 1.8 to 2.8 seconds.

The ejection cycle can be initiated in two ways:

- Pulling on the D-ring at the front of the seat
- Raising either or both leg braces and squeezing either or both exposed triggers

The system includes automatic torso positioning and restraint, a contoured-lid survival kit with automatic kit deployment and inflation of life raft, a contoured automatic lap belt, a high-impulse rocket motor with integral seat/motor adjustment for minimum c.g. excursion, a forced seat/man ballistic separator, a backup system for the conventional seat/man separator, a seat retardation system to prevent seat/man/chute involvement, and a forced-deployment personal parachute system initiated one second after lap belt release.

Equipment Comparison. -The differences between Communications and Navigation equipment complements were investigated for a new aircraft and for a modified existing aircraft. In the case of the new aircraft, commercial, solid state units were selected. Existing GFE units, where applicable, were taken for the modified aircraft, assuming the military (T-39A) equivalent to the Sabreliner for equipment selection.

From a review of the electronic complement of the new and modified aircraft, shown in Table 13, it may be seen that the new design equipment represents a significant reduction in both weight and volume penalties. The further advantages of a new complement are: better reliability, maintainability and power consumption. This is achieved through the extensive use of solid state circuitry and modular design. Since the existing T-39A aircraft ARN-21C TACAN set must be replaced by the required DME unit, the net cost savings offered by using the remainder of available GFE equipment is considered to be nominal.

TABLE 13A. EQUIPMENT LIST - Communications Subsystem

	NEW DESIGN (C)	WT (LB)	VOL (IN.^{3})	MODIFIED T-39 (J)	WT (LB)	VOL (IN.^{3})
VHF TRANSCEIVER	618M-1A TRANSCEIVER	19.0	469	17L-7A TRANSMITTER	15.0	413
	313N-3 CONTROL (2)	2.0	65	51X-2B RECEIVER	10.5	341
	137X-1 ANTENNA	6.0	N/A*	614U-6 CONTROL (2)	2.5	76
	390Y-2 SHOCKMOUNT	1.7	72	390E-2 SHOCKMOUNT	3.1	272
				37R-2U ANTENNA	2.5	N/A*
	TOTAL	28.7	606	TOTAL	33.6	1,102
ATC TRANSPONDER	621A-3 TRANSPONDER	25.2	732	- NEW EQUIPMENT REQUIRED -		
	TBA CONTROL (2)	1.5	48	ASSUMED SAME AS		
	350E-3D SHOCKMOUNT	2.1	96	FOR NEW AIRCRAFT		
	237Z-1 L-BAND ANTENNA	0.2	N/A*			
	TOTAL	29.0	876	TOTAL	29.0	876
AUDIO CONTROL UNIT	387C-4 AUDIO AMPL (2)	1.6	65	AIC-10A AUDIO AMPL	4.0	140
				CONTROL (2)	1.5	65
	TOTAL	1.6	65	TOTAL	5.5	205
	UNIT TOTALS	59.3 LB	1,547 IN.^{3}		68.1 LB	2,183 IN.^{3}
* EXTERNALLY MOUNTED	TOTALS ADJUSTED FOR CONTROLS DIFFERENCES	64.4 LB	1,735 IN.^{3}		72.1 LB	2,324 IN.^{3}

TABLE 13 B. EQUIPMENT LIST - Navigation Subsystem

	NEW DESIGN (C)	WT (LB)	VOL (IN^3)	MODIFIED T-39 (J)	WT (LB)	VOL (IN^3)
COMPASS SYSTEM	C704130 GYRO COMPASS & AMPL	9.2	425	C704130 GYRO COMPASS & AMPL	9.2	425
	DT-173/AJN FLUX VALVE	3.0	50	DT-173/AJN FLUX VALVE	3.0	50
	COCKPIT CONTROL (2)	1.0	40	COCKPIT CONTROL	1.0	40
	TOTAL	13.2	515	TOTAL	13.2	515
VOR-ILS LOCALIZER RECEIVER	137X-1 ANTENNA	N/A*	N/A**	37R-2U ANTENNA	N/A*	N/A**
	51RV-1 VOR-LOC-GS RECV'R	18.5	473	51X-2B VOR-LOC RECV'R	N/A*	N/A*
	390Y-1 SHOCKMOUNT	1.7	130	390-E2 SHOCKMOUNT	N/A*	N/A*
	TOTAL	20.2	603	TOTAL	N/A	N/A
ILS GLIDE SLOPE RECEIVER	37P-4 ANTENNA	0.7	N/A**	37P-3 ANTENNA	0.7	N/A**
	PART OF 51RV-1 RECV'R	N/A*	N/A*	390-R2 SHOCKMOUNT	0.6	64
				51V-3 GLIDE SLOPE RECV'R	6.3	214
	TOTAL	0.7	N/A	TOTAL	7.6	278
MARKER BEACON RECEIVER	51Z-4 MARKER BEACON RECV'R	3.3	178	51Z-2 MARKER BEACON RECV'R	5.0	92
	37X-2 ANTENNA	0.3	N/A**	37X-2 ANTENNA	1.0	N/A**
	390R-1 SHOCKMOUNT	0.6	55	390R-1 SHOCKMOUNT	0.6	55
	TOTAL	4.2	233	TOTAL	6.6	147
DISTANCE MEAS EQUIP OR TACAN	237Z-1 ANTENNA	0.2	N/A**	ANTENNAS (2)	1.0	N/A**
	313N-3 CONTROL (2)	N/A*	N/A*	C866 CONTROL	1.5	62
	860E-2 TRANSCEIVER	36.0	732	CV-279 DET. NETWORK	3.0	40
	350E-3D SHOCKMOUNT	1.5	200	RT-220 & MT928 RECV'R & MT.	62.5	2,105
	TOTAL	37.7	932	TOTAL	68.0	2,207
	UNIT TOTALS	76.0 LB	2,283 IN^3		95.4 LB	3,147 IN^3

* INCLUDED IN COMMUNICATIONS SUBSYSTEM

** EXTERNALLY MOUNTED

Program Flow - Concepts C and J

The program flow for Concepts C and J are predicted to be very similar because the controlling events (delivery of engines and variable stability systems) are common to both.

The first critical event, for both concepts, is release of specifications and purchase orders for engines after the first month. Necessary detailed engineering of the VSS will delay release of the specification until the end of the third month, and the purchase order until the middle of the fifth month. Earliest delivery of the VSS is estimated after 16 months, and of engines after 17 months.

For Concept C, particularly, early wind tunnel tests are required. This will necessitate the issuance of a purchase order after one month for use of a wind tunnel facility and test support. Critical to Concept J are early availability of Sabreliner engineering data, and receipt of new skeleton airframe parts at the modification facility by the fifth month.

If the above events occur as scheduled, either configuration can be ready for first research flight after 30 months.

Summary Comparison

Concept C has the highest research utility. It has fewer engines, superior crew station design, better flying qualities, better level of lateral stability during transition, and better growth capability. It meets all NASA ground load and sink speed requirements, an important consideration in the operation of V/STOL aircraft. The structure is designed for ease of maintenance, accessibility to research payload and uses conventional aluminum alloys with good fatigue properties, low crack propagation, and good strength recovery after exposure to temperature. The structural changes to Concept J are so extensive that in point of fact it approaches a severely compromised new airframe design. The primary wing structure and fuselage longerons of Concept J use aluminum alloy 7178T6. This particular alloy has been banned by the U.S. Air Force for use on the US/FRG V/STOL aircraft. Some of the quantitative relationships between the aircraft are shown on Table 14.

TABLE 14. SUMMARY COMPARISON OF A NEW AND A MODIFIED AIRCRAFT

Item		Concept C	Concept J
1	Weight	15,300	19,760
2	Engines (YJ85-GE-19)	2 L/C + 6 L	2 L/C + 8 L
3	Differential Program Cost, $	+ 1.64M	-
4	Utility Rating	46	1
5	Operational Factor	79	39
6	Hover Time (Basic)	14.0	12.0
	Hover Time (Pure Lift)	11.3	10.2
7	Load Factor (Flight)	3.75	3.0*
	Load Factor (V/STOL Landing)	3.29	2.43
8	Sink Speed (ft/sec)	15.0	11.3
9	Stall Speed Spread (Knots)	40	8
10	Max. Lift Coefficient		
	(Flaps Extended)	1.96	1.68
	(Flaps Retracted)	1.3	1.46
	(Flaps Retracted, Lift Spoiled)	1.0	
11	Ferry Range (Nautical Miles)	540	435
12	Take-Off Distance (S. L. 80°F)		
	Ground Run (ft)	2100	2700
	Clear 50 ft (ft)	3300	4500
13	Rate-of-Climb (S. L. 80°F) ft/min	6000	4200
14	Max. Airspeed (S. L.) Knots	575	520
15**	Rate-of-Climb with Single Engine Out (S. L. 80°F) ft/min	150	80

* Capability of existing T-39 (stretched version). All areas and components affected by modification to be stressed for 1.25 x 3.0 g loads.

** Approach flap condition, lift engine doors open, engines windmilling.

CONCLUSIONS

The results of the conceptual design study indicate that a new V/STOL aircraft design will provide considerably greater research utility than a modified aircraft and will meet all NASA specified requirements.

The new aircraft can be delivered in the same schedule and for only a nominal increase in total program cost and will have the following advantages:

- A more representative cockpit design
- Better visibility
- Better margin of hover control
- Greater hover endurance
- Considerably better range of stall speeds
- Less weight growth sensitivity
- Better crew escape (because of the tandem arrangement)
- Fewer engines to control and maintain
- An existing diverter valve design
- Lighter and simpler hover control system
- Lower tire temperature
- Higher sink speed capability
- Better conventional-flight flying qualities
- Proper provisions for use of a sidestick controller

BIBLIOGRAPHY

Anon, NASA Statement of Work L-7151- V/STOL Jet Operations Research Airplane Design Study, Langley Research Center, June 1966.

Anon, Recommendations for V/STOL Handling Qualities (with an addendum containing comments on the recommendations), AGARD Report 408A, October 1964.

Koven, W., and Wasicko, R., Flying Quality Requirements for United States Navy and Air Force Aircraft, AGARD Report No. 336, April 1961.

Anon, Model Specification E 1129 Engine, General Electric Company, November 1966.

Anon, Preliminary Project Performance - RB162-81, Report PP183, Rolls Royce Ltd., December 1965.

Anon, Charts; Standard Aircraft Characteristics and Performance, Piloted Aircraft, MIL-C-5011A, November 1951.

Anon, Flying Qualities of Piloted Airplanes, MIL-F-8785 (ASG), September 1954.

Anon, Airplane Strength and Rigidity, General Specification for MIL-A-8860 (ASG) May 1960.

Anon, Airplane Strength and Rigidity Landplane Landing and Ground Handling Loads, MIL-A-8862 (ASG), May 1960.

Anon, Structural Design Requirements, Helicopters, MIL-S-8698 (ASG), July 1954.